CONSTRUCTION AND DEMOLITION WASTE IN WESTERN AUSTRALIA: A CASE STUDY ON BEST PRACTICE DEMOLITION

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Declaration

I declare that this thesis has been composed solely by myself and that it has not been submitted for any other previous application for a degree; except where stated otherwise by reference or acknowledgement.

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ABSTRACT

The C&D waste sector is the only sector in which waste generation has increased in Australia, and most recent data shows WA diversion of C&D waste from landfill to be 57% [1, 2]. This is low compared to countries such as Japan and the Netherlands which achieve diversion rates of 97% and 95% respectively. In addition to this, the extraction and production of raw construction materials can result in large amounts of greenhouse gas emissions which are harmful to the environment. The reuse and recycle of C&D materials can help to alleviate both problems and as such WA's transition towards a circular economy is of high importance to the current waste industry.

The aim of this study is to identify barriers and opportunities which contribute to a higher rate of reuse, recycle and recovery in best practice demolition, and the transition towards a circular economy in the C&D sector of WA. The Hamilton Senior High School (HSHS) demolition was chosen as a case study due to the use of best practice demolition techniques, including onsite crushing activity and direct recycle/reuse. The four objectives achieved under this study include:

1. Gain an understanding of current issues or innovations within the C&D waste sector;
2. Identify the waste contribution of the HSHS demolition to the WA waste stream and stockpiling, and if this could be further improved;
3. Determine the environmental impacts/savings of conducting a demolition and potential construction using WA best practice;

4. Determine the economic viability of conducting best practice demolition in WA

The methods chosen to achieve these objectives were industry surveys, total waste quantification at the HSHS site, environmental impact assessment via carbon footprint, economic assessment via cost benefit analysis, and a comparison to a business as usual and worst case scenario.

Successful achievement of the objectives identified a significant problem with illegal disposal practices occurring to avoid landfill levy payments. Lack of regulation, voluntary reporting, lack of economic incentive (including market for products) and ineffective landfill levy application to regional areas were also identified to be barriers to higher recycle and reuse. Results also displayed the environmental and economic benefits of this demolition. Best practice techniques resulted in the highest net GHG abatement (327 tCO_2e), low contribution to the C&D waste/stockpiling streams (10200 t, or 92.7% recycled material), and cost savings generated by lower raw material use, transport and waste fees (saving approximately $252,000). The HSHS demolition was however, the most expensive scenario, with approximately $1,900,000 comparable costs.

Further research could be conducted on the application of higher direct reuse and possibly design for deconstruction to improve material circularity. It is recommended that regulation surrounding the landfill levy should be put in place to discourage illegal practices. In addition, economic incentive could be provided in the form of lower labour taxes, and higher raw materials tax to encourage best practice demolition techniques.

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ABBREVIATIONS

ACM – Asbestos Containing Material

ARCP – Asbestos Removal Control Plan

BAU – Business as Usual

C&D waste – Construction and Demolition Waste

CE – Circular Economy

DWER - Department of Water and Environmental Regulation

GWP – Global Warming Potential

HSHS – Hamilton Senior High School

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LCIA – Life Cycle Impact Assessment

LCC- Life Cycle Costing

MDF- Medium-density fireboard, an engineered wood product often used in furniture such as school desks

MSW – Municipal Solid Waste

TBL – Triple Bottom Line

UDIA – Urban Development Institute of Australia

WCS – Worst Case Scenario

1 INTRODUCTION

1.1 BACKGROUND

Construction and demolition (C&D) waste is generated from construction, repair, maintenance and demolition activities [3]. This waste generally consists of variable types of materials, largely dependent on site characteristics such as age, size, source (commercial, residential or industrial), location, and type/method of activity (construction, demolition, renovation or repair) [4, 5, 6, 7]. Despite the variability of C&D waste characteristics, it usually consists of a larger percentage of bricks and concrete (80-83%), then metal, timber, a small amount of plastics, paper, cardboard, tiles, glass, contaminated materials and overburden (such as rocks, clay and asphalt from excavation activities) [5] [3]. The variation in site characteristics usually brings about different proportions of these materials, and it is often hard to predict the constituents of C&D waste based off the demolition activity of different sites.

C&D waste currently accounts for the largest proportion of Western Australia's waste stream (38% in 2016), and is often the focus of recovery and recycling efforts due to this [1]. This sector of waste in Australia is the only sector in which generation has increased (by 2% per capita) in the past decade, where other sectors have decreased in generation by up to 17% [2, 8]. WA diversion of C&D waste from landfill sits at 57% (2015-16), where countries such as Japan and the Netherlands can achieve a higher 97% and 95% respectively [1, 9, 10]. Demolition projects generate a larger quantity of waste than construction or renovation projects, a rate of around 10 times higher, and is often the area of focus for waste management initiatives [4]. In addition to this, the production of raw materials for construction projects often results in harmful impacts to the environment, and recycling of C&D waste can help to alleviate this. The composition of C&D waste is often highly variable, however Felmingham's thesis provides insight into possible composition of residential C&D waste generation (however, this did not investigate commercial demolition) [5].

Australian greenhouse gas (GHG) emissions from the waste sector account for a small proportion of overall national emissions (2.3%), which also includes emissions derived from Municipal Solid Waste (MSW) and the industrial waste sector [11]. This percentage is not alarming, however when including emissions derived from the processes involved in the production/extraction of raw construction materials, this can account for a larger 25.5% [11]. The extraction and production of raw materials (such as those needed for concrete, bricks, metals, road construction) contributes to a large proportion of the embodied carbon derived from construction (and demolition) activities. Further, a previous study conducted in 2017 showed materials and construction activity to account for a combined 29% of the carbon footprint derived from the construction sector (second to emissions from electricity use) and suggested an increase in recycling could reduce this number [12].

In a world concerned about climate change derived from the emission of harmful greenhouse gases (GHGs) and the rapid depletion of raw material availability, there is a need to change the practices which lead to excessive waste generation. Compared to globally achieved C&D waste diversion rates, WA has a way to go to improve recycling and reclamation of materials throughout the waste stream to alleviate emissions and raw material use pressures.

1.1.1 CASE STUDY SITE DESCRIPTION

The object of this case study is the demolition and redevelopment of the former Hamilton Senior High School (HSHS), 17km from the Perth CBD in Hamilton Hill and currently owned by Landcorp. The construction site is approximately 12 hectares, bound by Ralston street to the north, Purvis street to the west, Stock road to the east and Forest road to the south. Nine main buildings (labelled A through to I in Figure 1) will be demolished, excluding the demountable Building A which will act as the site office until most of the construction is complete. Figure 1 shows the demolition plan provided by Tabec Engineers. The full demolition method will be observed and recorded as part of the results for this thesis, and is presented in Section 4.1.

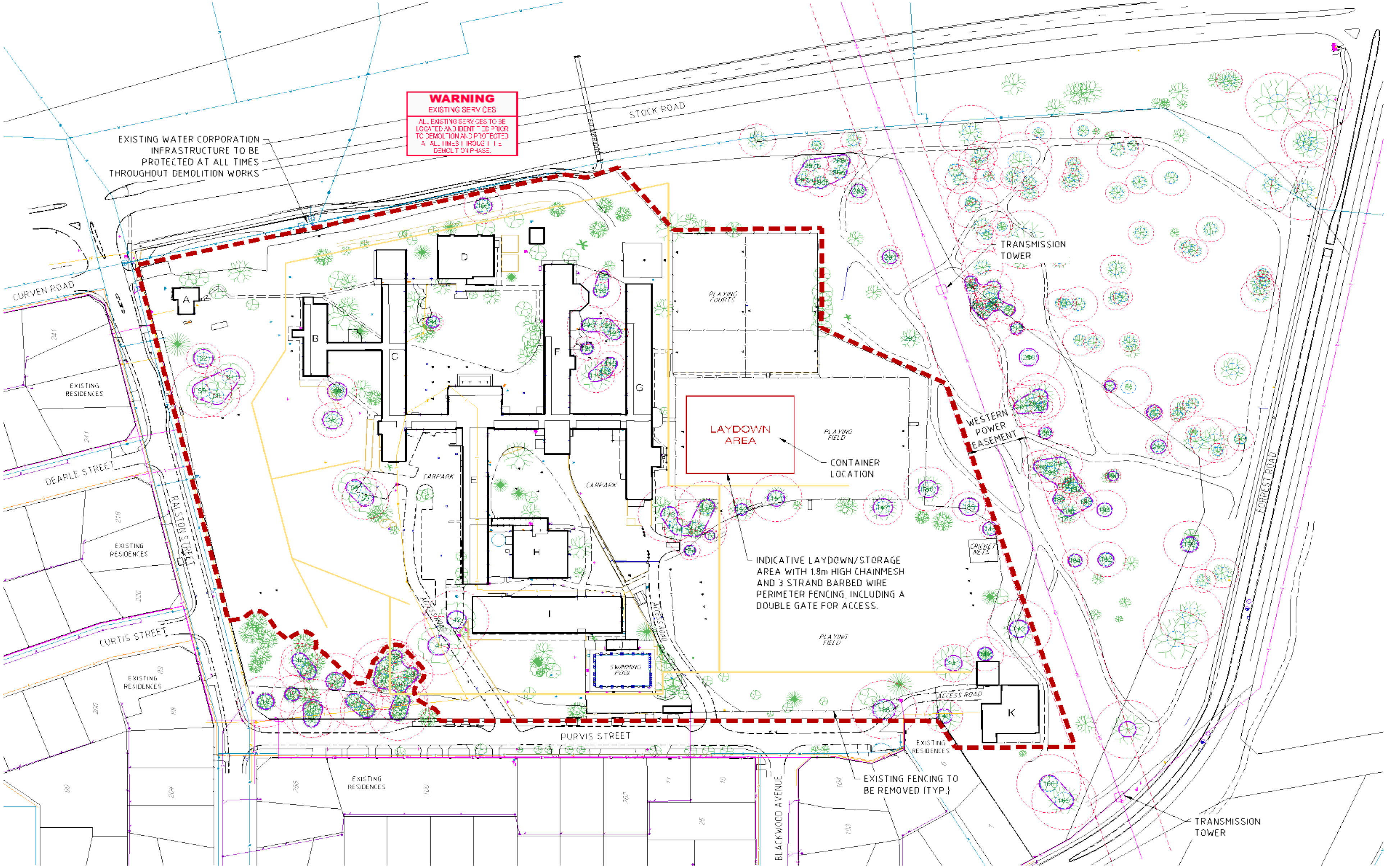


FIGURE 1 HSHS DEMOLITION BUILDINGS AND SITE PLAN

SOURCE: TABEC (WITH PERMISSION)

The proposed construction will be a residential development, with 227 lots to consist of 308 dwellings of R40 to R80 housing (as per the most recent information available during this thesis). Two mixed use areas will also be included in the redevelopment with 17% public open space (POS), 7% more than is required. Landcorp is aiming to meet the Urban Development Institute of Australia's (UDIA) Envirodevelopment certification, and recycle 90% of the C&D waste generated onsite. Envirodevelopment certification is a nationally recognised, scientifically based certification and branding system which verifies a development's sustainability performance [13]. Envirodevelopment certification by the Urban Development Institute (UDIA) of Australia is given to developments which can achieve outstanding performance in four or more of their six elements of sustainability (water, energy, community, materials, waste, ecosystems). Envirodevelopment states that its certified developments "will have been carefully designed to protect the environment and use resources responsibly, whilst offering a range of benefits to homeowners, industry and government" [13].

The demolition at HSHS will use best practice demolition techniques (as defined in Table A 6 in Appendix 2) with onsite crushing, aiming to reduce waste generation and conduct construction with as much reuse and recycle of onsite materials as possible. It was because of these reasons that the HSHS demolition was deemed suitable for study in this thesis. These methods are deemed best practice, due to their success in international C&D waste management, and achieving reduced impacts.

1.2 AIM AND OBJECTIVES

The opportunity to study HSHS was presented to Murdoch by Landcorp, who have aimed to conduct this C&D project with leading sustainable practices in Western Australia. The aim of this research is to identify barriers and opportunities that contribute to a higher rate of reuse, recycle and recovery in best practice demolition, and the transition towards a circular economy in the C&D sector of WA. The best practice measures of this case study could act as an example for future projects, to enable higher diversion of C&D waste from landfill and lower raw material use in construction projects. Using HSHS as a case study will help to achieve this aim, with specific objectives:

1. Gain an understanding of current issues or innovations within the C&D waste sector;
2. Identify the waste contribution of the HSHS demolition to the WA waste stream and stockpiling, and if this could be further improved;
3. Determine the environmental impacts/savings of conducting a demolition and potential construction using WA best practice;
4. Determine the economic viability of conducting best practice demolition in WA

2 LITERATURE REVIEW – C&D WASTE BACKGROUND

Recycling of wastes derived from smaller-scale residential construction has been well investigated and higher rates of recycle and reuse have been achieved in this area, however this has not been the case for larger scale industrial or commercial projects [14].

2.1 INTERNATIONAL AND NATIONAL C&D WASTE MANAGEMENT

2.1.1 INTERNATIONAL

It is important to look at C&D waste in a global context, to draw from countries that are implementing successful C&D waste management strategies, and to learn from those that are not so successful. In considering the successes, it is important to also consider the social and political climate of the country which can largely influence the effectiveness of these management strategies [15]. Among the most successful for best C&D waste management practices are Japan, Netherlands, Germany and San Francisco, with Europe displaying mixed results across its member countries [4]. Spain and China are amongst the worst performing. Many international studies have accepted that onsite recycling of crushed aggregate results in less environmental impacts and is sometimes less costly than landfill or offsite recycling scenarios, however these studies often differ in boundary and scope of analysis, and very few are available for West Australian case studies [4]. One of the major factors hindering effective C&D waste management is the lack of economic incentives for correct C&D waste management [16].

The following has been summarised to contribute to effective global C&D waste management:

- Europe has introduced a regulatory framework for data control, leading to more reliable, higher quality data collection [17]

- To reduce the impact of economic barriers it has been suggested to increase the taxes on use of primary raw materials, and lower tax on labour to create a higher demand which is a technique employed by Japan [4]

- Significant cultural and social factors contribute to effective C&D waste management in San Francisco and Japan [4]

- Social factors such as Japan's "*mottainai*": cultural ideology of taking only what is needed and wastefulness regarded with shame and regret. Suggested to have improved acceptance of the Fundamental Plan, which uses the 3R concept (Reduce, Reuse, Recycle) for effective waste management [18]

Table A 1 in the Appendix shows a summary of global legislation, with the respective percentages of C&D waste diversion in a global context. Contributing or inhibiting factors for successful C&D waste management are shown in Table A 2 in the Appendix. In addition to these factors, the recent implementation of the National Sword programme introduced by China is set to change current Australian recycling practices, and encourage adoption of a circular economy. China previously accepted 1.25 million tonnes of waste, however the programme aims to limit the amount of solid waste accepted from January 2018 onwards. This could lead to an increase in the provision of waste processing facilities across Australia, and further incentives that help to alleviate the pressure on local governments to deal with this extra waste. This is important for adopting a circular economy for waste management [19]

2.1.2 NATIONAL CASES AND REPORTING

Australia's C&D waste generation has increased in the past decade and recently produced 19.5 million tonnes of C&D waste in 2014, with around 12 million tonnes recycled [20]. The National Waste Strategy (2009) asked for publishing of national reports every three years since its establishment, and there have been three reports published regarding the national Australian waste sector for the years 2010, 2013 and 2016. All reports are regarded to have incomplete, unreliable and inaccurate data [21]. Despite this the national reports are the most comprehensive representation of national Australian waste and recycling activity so far [21].

Previously, the Australian Bureau of Statistics (ABS) produced several publications regarding national Australian waste management, regarded highly for accuracy and usefulness. The Waste Account by the ABS integrated monetary and physical information using "an internationally recognised framework to assist in informing waste policy and discussion in Australia", however due to budget cuts the ABS no longer produce these publications [21].

Through Blue Environment's analysis of national reporting methods, it was found that better reporting and accurate data gathering methodology across all states is needed for an accurate discussion of the waste sector across Australia, and will allow for informed decisions to be made regarding this data. Possible reintroduction of the ABS Waste Accounts could help this issue, and standardisation of data collection with uniform definitions of waste. Blue Environment suggests 65 improvements to address these issues in their report of national waste data [22].

2.2 C&D WASTE IN WESTERN AUSTRALIA

WA diversion of C&D waste from landfill sits at 57% (2015-16) [1]. Despite this, the most recent WA waste report states that WA has achieved the 75% recycling rate by 2020 target set by the Waste Strategy: Creating the Right Environment (2012) [1].

2.2.1 COMMON PRACTICE C&D WASTE MANAGEMENT IN WA

This section outlines what is common practice in C&D waste management in WA, often termed "Business as usual" (BAU) Currently, only 49% of Western Australia's waste is weighed via weighbridges in Metro WA, with regional quantities unknown. This is far below the 70-100% seen in states over east, and reduces the reliability of waste data quality for WA. In addition, large amounts of waste stockpiling activity have been suggested to occur, which is a further concern as the activity is currently unmonitored despite the availability of useful technology (such as weighing devices attached to loader buckets which could account for the weight of material in each stockpile) [2]. This reflects the lack of market for C&D products in WA, which is predicted to improve through a trial of C&D product use in civil projects such as the Kwinana Freeway widening by Main Roads [2]. This is part of the Roads to Reuse (RTR) pilot, and will use approximately 25,000 tonnes of C&D product in construction. Future research should analyse how the introduction of this trial has impacted C&D recycle rates.

It is known that co-mingling waste on demolition sites is common practice for demolition projects in WA, with some source separation occurring for larger demolition activities when economically beneficial. Separation usually occurs for metals, as the recycle of this material is often economically beneficial for the demolition company. This is a step in the right direction, however metals only usually make up a small proportion of the waste output from demolition activity, with masonry materials usually accounting for a much higher percentage.

2.2.2 LEGISLATION

The WA Waste Authority and Department of Water and Environment Regulation (DWER) are the main governing bodies concerned with waste management in WA. The Waste Authority was established under the Waste Avoidance and Resource Recovery (WARR) Act, and DWER under the Environment Protection (EP) Act 1986 [23]. These bodies provide guidance on policy and waste strategies to local government. One such association is the Western Australian Local Government Association (WALGA), which has created committees such as the Municipal Waste Advisory Council (MWAC), which can represent WALGA for matters regarding solid waste. Local governments usually have their own legislation relating to the WARR Act, however not many have specific legislation for C&D waste [5]. A summary of relevant legislation is included in Table A 3.

WA policy and legislation needs to address the following issues:

- Explicitly specify the use of recycled C&D waste products in policies, procurement and tender documents;
- Re-processors need to educate and provide markets with high quality, consistent C&D waste product;
- Continue to partner with large projects (such as the Kwinana Freeway widening from Main Roads WA), and possibly introduce legislation to mandate specific reuse of C&D waste in future construction projects;
- Educate waste generators and contracted companies on how/where C&D waste materials can be recycled, and the cost comparisons between using these products compared to BAU;

- Improve data collection and reporting requirements at waste facilities, which includes stockpile accounting.

2.2.3 RECENT DEVELOPMENTS IN WA

Recently, Main Roads WA are working with DWER and the WA Waste Authority to trial the use of 25,000 tonnes of recycled C&D waste in the widening of the Kwinana Freeway in WA under the RTR pilot previously mentioned. Trials like this will be beneficial in increasing future C&D waste recycle, and if successful this number will be increased to 100,000 tonnes [24].

The February 2019 release of the Waste Avoidance and Resource Recovery Strategy 2030 placed heavy emphasis on WA's transition towards a low waste, sustainable, circular economy. In addition to the RTR pilot, new waste data and reporting requirements as amendments to the WARR Act 2008 have been highlighted as priority actions for the 2018-2019 and 2019-2020 financial years. This is set to include an online reporting system to be implemented by 2020, and could enhance reliability of WA waste data [24]. Importantly, the strategy also outlines the quantification of stockpiling activity, which has become a problem for WA as identified by the Latest National Waste Report (2018) [2].

2.3 BARRIERS INFLUENCING EFFECTIVE C&D WASTE MANAGEMENT

2.3.1 GLOBAL BARRIERS

The following can be summarised for ineffective C&D waste management areas in a global context:

- European waste management receives some of the same criticisms as Australia (for the definition of wastes and clarity of reporting), along with a lack of confidence in C&D waste product quality in some countries [6, 25]
- Similarities exist between Japan and Australia in terms of the economic barriers present. Higher prices of recycled concrete products compared to the lower prices and high availability of virgin raw materials, and lack of market for these products are the main barriers to effective C&D waste recycle [4]
- Spain experiences educational and informative barriers, along with low social acceptance of regulations placed on on-site C&D waste practices due to knock-on negative economic impacts [4]
- China has a lack of recycling facilities available, and most of its C&D waste is incinerated or landfilled [4]
- The low cost of C&D waste disposal represents another barrier in China (0.46-0.76 USD in China compared to 9.60 USD in Japan and 5-15.00 USD in the USA) [26] – although it was suggested in both sources that increasing this could increase illegal dumping, and strict regulatory measures need to be put in place in addition to raising the cost of C&D waste disposal to discourage this
- China also experiences a lack of urban planning – this increased demolition rates leading to lower life expectancy of buildings, some even being unoccupied upon demolition (35 years life expectancy in China, compared to 132 years in the UK). [4]

2.3.2 WESTERN AUSTRALIAN BARRIERS

The collection of data in WA regarding landfill, resource recovery and recycling is via four different data sources and is not reconciled, which can cause confusion as to what the recovery rates are, versus what is reported [21]. Harris identified the Eclipse vs. the State case which would be influential in shaping attitudes towards C&D waste recycling [23]. Uncertainty regarding the definition of "waste" was the main cause for concern in this case, and the decision to force the company to pay millions in landfill levies had caused significant uncertainty in C&D waste recycling activity.

The main barriers found for effective C&D waste management in WA include:

- Ineffective, incomplete and unreliable data reporting and collection methods
- Illegal dumping and stockpiling
- Lack of market for recycled C&D waste products
- Lack of government (at all levels) policies, specifications or tenders which specifically state the use or purchase of recycled C&D waste products is necessary (with some local exceptions, such as Geraldton)
- Lack of awareness of builders as to what, where and how to recycle C&D waste, and where cost savings can be generated
- Lack of source separation, specifically on site for larger demolition projects

[23, 5, 20, 21, 27, 2]

Although diversion rates of C&D waste from landfill are high, the actual generation of C&D waste is not decreasing in WA [2, 8, 18]. Despite this, policy has been continuing to move from preventing waste generation to focussing on developing a sustainable materials policy for C&D waste diversion [18]. Although the diversion and subsequent recycle of C&D waste is important, tackling the generation of C&D materials should still be a focus of waste management, especially as the new Waste Strategy 2030 still holds the waste hierarchy as an important framework to follow (with avoiding generation of waste being the most preferred option) [24].

2.3.3 CONTAMINATION WITH ASBESTOS

Asbestos is a hazardous material, and presents a significant barrier for C&D waste recycle in demolition as it can contaminate otherwise clean, recyclable material. Demolition of older buildings usually must consider the presence of hazardous materials due to their much higher use during the time of their construction [28, 29]. The use of asbestos has been banned since 2003 due to the health risks involved, and demolishing buildings with asbestos can be hazardous [28]. Removal of asbestos is time consuming and expensive, with asbestos materials needing to be disposed of only at licensed landfills. In addition to asbestos, lead paint can interfere with the recycling of otherwise recyclable products, such as lead paint on doors, frames, railings or concrete. The testing involved, additional labour costs and correct disposal all add to the expenses in ensuring C&D waste are not contaminated, and as such the presence of materials contaminated with these harmful substances on a site can present itself as a significant barrier to effective C&D waste recycling [28].

On-site crushing is heavily impacted with asbestos risks, as the crushing can cause particles to become airborne. Therefore, Local Governments are hesitant to provide on-site crushing approvals for demolition on sites impacted by asbestos due to the high liability of these operations, and doing so can often take extended periods of time which push back demolition timelines and hinder on-site recycling efforts because of this [28]. Cardno has identified communication and education on correct contamination removal processes to be one factor in overcoming this barrier for effective C&D waste management in older buildings [28].

Recently, NSW has introduced new fines (via the Protection of the Environment Operations Legislation Amendment (Waste) Regulation 2018) to reduce the illegal disposal and transport of asbestos, increasing fines from $750 to $7500 for an individual and from $1500 to $15000 for a corporation [30]. Measures like this are set to discourage asbestos contamination in C&D waste.

2.4 METHODS OF DEMOLITION AND RECYCLING

Different methods of demolition can enhance C&D waste materials recycle. These can include:

- Source separation (unconventional demolition, or selective demolition),
- co-mingling waste (destructive or conventional demolition)
- a combination of the two

[4]

Co-mingling of waste is the practice of piling all waste materials into one waste pile (i.e., metals mixed in with wood, concrete, bricks). The waste is usually sent off site for processing, involving mechanical sorting processes before the individual materials are recycled.

Source separation is a technique that usually occurs at the site of waste generation. It involves manually sorting different types of waste as they are generated so that they can travel to recycling facilities (i.e., bricks from metals, timber, tiles, concrete) in their respective waste streams. This ensures that the recycle of each material can be performed with less contamination of other materials and therefore higher efficiency, as it reduces the amount of mechanical sorting needed further down the waste processing line, and if performed effectively it could even eliminate the need for mechanical processing in the future [31]. Cost benefits for demolition companies are also derived from this method, as processing facilities often charge more for mixed waste, compared to separated waste due to the extra mechanical processing required.

Demolition which separates C&D waste materials at the source have been found to be better in an environmental assessment, however not always in an economic assessment (although there are cases where it has been found to save more money and generate more profit) [4]. Source separation has also been found to improve C&D waste recyclability from a range of papers, through improving end material quality, which also has implications on the confidence that end users have in recycled products. This therefore also enhances economic factors by improving the market for recycled materials [31].

It has also been stated that source separation requires less effort and is more effective in waste segregation, compared with sorting mixed waste on or off-site [32]

2.5 THE CIRCULAR ECONOMY

The circular economy (CE) within the C&D waste context was a common topic discussed in many papers, and is recently included in the new WA Waste Strategy [24]. It is sometimes referred to as industrial ecology, or industrial symbiosis [33]. The circular economy framework for waste management is the principle that materials will flow in a closed loop system, in which waste generated at one stage of the loop can be used at another stage to enhance efficiency of resource use, waste management and reduce climate change impacts, and is often linked to a zero-waste goal because of this [34, 35]. The National Waste Report also describes it as always keeping products, components, and materials at their highest utility and value [2]. CE is a main objective for the EU, China, Japan, and more recently a focus of WA's Waste Strategy 2030. As C&D waste recovery rates are highly variable (across the EU E.G. compare Spain to the Netherlands) it is suggested that due to various barriers it has not been properly implemented [4]. It has been recommended that the National Waste Policy for Australia needs updating to include specific strategies for establishment of a CE, to prioritise the collection, recovery and re-use of C&D waste products [21].

Lee et al. (2017) suggests that we need to start thinking about waste as a resource rather than a problem, which is the current approach, and represents an attitudinal barrier not only for CE implementation but for C&D waste management as a whole [10]. Barriers to adopting a CE for waste management were also investigated by Mahpour (2018), finding 22 potential barriers in behavioural, technical and legal perspectives. Ghisellini et al. (2018) also identify barriers under these headings which can prevent effective C&D waste management [4]. Of the 22 barriers found by Mahpour, the most important barriers to CE under the three headings were found to be:

- Behavioural:
    1. Using finitely recyclable construction materials;
    2. Inadequate policies and legal frameworks to manage C&D waste as well as lack of supervision on C&D waste management.
- Technical:

1. Ineffective C&D waste dismantling, sorting, transporting and receiving processes;
2. Inadequate awareness, understanding and insight into CE in C&D waste management.

- Legal:
    1. Using finitely recyclable construction materials;
    2. Inherent complexity in transforming into a CE in C&D waste management.

[36]

Often materials processing is required for one waste to be useful at another stage for a CE ("recycle" in the waste hierarchy), and is also one of the main sources of disincentive in CE. The energy input to processing can act against overall sustainability goals [14, 34]. If a product can be designed with recycling in mind for another stage in the CE, then closing the loop for a CE will be more effective [10]. Factors which will improve adoption of a CE:

- C&D waste products need to be high quality, and of high value (creation of markets)
- A combination of citizen and industry engagement (and changing of attitudes and influencing behaviour towards sustainable waste practices)
- Integrated infrastructure development

[10, 21]

Allwood (2014) investigates the feasibility and attitudes surrounding a CE. Table A 4 in the Appendix summarises the feasibility of applying CE concepts to various materials. Allwood suggests reducing materials demand in combination with preparing social mindsets for demand regulation are both areas for greater future development, and places emphasis on not losing sight of the overarching sustainability goal, which is sometimes lost in innovating towards a CE instead of towards sustainability. [37]

2.5.1 DESIGN FOR DECONSTRUCTION/DISASSEMBLY AND THE ROLE OF REUSE IN A CIRCULAR ECONOMY

Crowther (2018) suggests that one of the main causes of high C&D waste generation is the short life expectancies of buildings and the layers within them (and the drivers to this including low economic, social and locational value of the buildings) [31]. This has been evidenced in China which has a low building life expectancy and high C&D waste generation [26]. To combat this, design for deconstruction is suggested as a construction strategy performed at the beginning of a building's life cycle to aid in demolition at the end of the building's life cycle, leading to greater direct reuse of building components [38, 31].

Reusing building components results in more energy savings than recycling and the potential embodied energy savings could be around 25-50% of total life cycle energy due to the lower energy needs generated from not having to reprocess materials at the end of life stages [14]. Examples of direct reuse in Australia have been found in Edge Environment's "*Construction and Demolition Waste Guide - recycling and reuse across the supply chain*" [33].

Designing for deconstruction can also enhance the quality of output C&D waste materials which further enhances the recyclability of those materials leading to an increase in material uptake [35, 31]. To improve the uptake of the design for deconstruction concept the following have been suggested:

Use prefabricated products, which can further reduce C&D waste in construction stages and enhance deconstruction during demolition [39]

Reduce the use of materials unable to be reused (such as dry wall) can further improve deconstruction and reduce C&D waste generation [38]

Future architects could produce deconstruction drawings to allow ease of deconstruction and enhance education on how these buildings need to be demolished [38].

Not only can specific elements be designed for reuse in demolition and construction projects, but whole building needs to also be considered for reuse for further reduction in C&D waste generation, where viable. Bullen explores this subject within a Western Australian context, suggesting extending building life (through a combination of improvement and conversion of the original building) is a more sustainable alternative to demolition ("adaptive reuse") [40]. In cases where density and plot ratios can increase from demolition of large buildings, and where the existing building is unsafe, then demolition is preferred.

2.6 CONCLUSIONS

The following points summarise the findings of this literature review:

- C&D waste management and generation is highly variable from site to site depending on a variety of factors, and is often hard to compare different site information due to this;

- WA C&D waste management faces some of the same international and national barriers as other counties, which need to be overcome to improve the C&D waste diversion rate;

- Data collection and reporting is an area for improvement across Australia and not just WA, and is one of the focuses of the new Waste Strategy 2030;

- Waste generation from demolition accounts for the largest proportion of C&D waste, and is usually comingled with a small amount of metal recycling motivated by economic benefits. Large amounts of stockpiling of this waste is becoming a problem;

- A lack of market exists for C&D products, however the WA Waste Strategy 2030 focuses on changing this through the RTR pilot and future local government incentive;

- Adopting a circular economy framework will be beneficial to the WA recycling effort, and efforts could be further improved with direct reuse and design for deconstruction.

- Environmental benefits can be derived from effective C&D waste management with source separation, onsite direct reuse and recycle. Economic benefits are more varied for different cases.

From analysis of available literature, it is evident that there are gaps in research. Research in the following areas is important to address with this thesis:

1. There is a lack of actual quantified data in WA regarding separated construction and demolition activities and associated material output. Providing this information will further help studies which aim to understand the nature of the C&D waste sector in WA;

2. Analysis of the social, environmental and economic impacts of best practice C&D waste management in WA, to identify areas of potential improvement and incentive for

future projects. Often analysis is performed at different sites with different scopes and boundaries of analysis which is difficult to compare;

3. Improvements in WA C&D waste management practices which can encourage a circular economy

3 METHODS RESEARCH

This section will be used to inform the selection of methods to be used in achievement of the objectives of this thesis. It is suggested that the performance of C&D waste management should be analysed holistically in the areas of environment, economy, quantification and social analysis [41, 7].

3.1 QUANTITATIVE METHODS

The following are methods used to quantify C&D waste across 57 papers from various regions:

- Site visits/direct onsite data collection
- Generation rate calculation (GRC)
- Lifetime analysis
- Classification system accumulation
- Variables modelling

(with "site visits" the only form of direct data collection) [29].

A description of these methods with comment on their usefulness is shown in Table A 5 of the Appendix. It is emphasised that where direct measurements of C&D waste generation can be made, it is the preferred option to gain useful, actual data, however it is not always the best option [29]. Objectives of measurement should always be considered when choosing the most appropriate method for C&D waste quantification [29, 42].

3.2 ENVIRONMENTAL ASSESSMENT METHODS

3.2.1 ENVIRONMENTAL IMPACTS

Renouf et al. identify the following midpoint indicators for environmental assessments in Life Cycle Assessment. These have been used to identify important areas of environmental assessment

The main categories of relevance to C&D environmental impact analysis have been identified to include:

- Climate Change (also termed "Global Warming" in some older assessments)
- Resource (abiotic) depletion – minerals
- Resource (abiotic) depletion – fossil fuels
- Water scarcity

[43]

These categories have been reordered to show the categories of greatest importance to an environmental impact assessment of C&D waste. Importance was judged using both relevance to C&D waste management and occurrence in literature. [43, 42]

The most common midpoint impact category assessed is "climate change", usually calculating greenhouse gas emissions or global warming potential (GWP) over a 100-year period [43]. As identified by the Australian Lifecycle Database Initiative (AusLCI) the most common unit for this is expressed as kg CO_2-e (or sometimes tonnes of CO_2-e), which is kilograms of carbon dioxide equivalent. It has been suggested that Australian best practice calculations in this category are to use the Australian National Greenhouse Assessment Methods, which utilise emissions factors [43].

3.2.2 ENVIRONMENTAL ASSESSMENT TOOLS

The most common method of impact assessment is a lifecycle assessment, used by approximately 40% of studies [43, 4]. Emergy Accounting (EA) and Lifecycle Energy Analysis (LCEA) have also been used to assess environmental impacts of C&D activities [4, 44]. LCEA measures direct and indirect energy consumption supporting a process [4]. EA is the measurement of exergy used directly and indirectly in transformations needed for a product or service [4]. Both methods have been seldom used in literature, and have limited applicability to this assessment.

3.2.2.1 LCA

LCA is defined as a methodology to determine the environmental impacts of the life cycle of products and services, and is the most widely used and preferred method for extensive environmental analysis [45]. Within this assessment methodology, a carbon footprint is usually calculated. It is an internationally accepted methodology, and often trusted to be objective in environmental performance measurement due to the standardised process (including the ISO 14040 series). The standard LCA method usually involves 4 main steps:

1. Goal and scope definition – includes system boundary and level of detail;
2. Inventory Analysis (LCI phase) – inventory of input/output data, and involves the data collection needed to meet the goals;

3. Impact Assessment (LCIA) – Provide additional information to help assess the LCI results to better understand their environmental significance;

4. Interpretation Phase – LCI and LCIA phases are summarized and discussed for conclusions, recommendations, and decision-making which should relate back to the goal and scope.

[45]

Although this standardised process is widely used, the comparison of results from an LCA is only possible if the assumptions and context of studies are the same, and therefore necessitates transparency throughout the assessment [42] [45]. A more in-depth analysis of LCA techniques also determined that a traditional LCA (sometimes referred to as "processed based" LCA) is often too complicated for smaller applications [46]. An LCA is often undertaken with the aid of complicated and sometimes expensive software (such as GaBi or Simapro, with application of appropriate databases such as AusLCI). Most LCA studies focus on the materials and operational stages throughout an LCA and often disregard activities occurring after demolition of a building, and is especially the case for streamlined LCA (SLCA) [47, 48]. Assessments often varied in terms of boundary, scope, goal and limits comparability of difference LCAs [48, 47, 42].

3.3 ECONOMIC ASSESSMENT METHODS

The WA Waste Strategy 2030 (2019) states that hundreds of millions of dollars of materials are lost to landfill each year, and systems in which materials are recovered, reused and recycled can reduce this impact [24]. Cost-benefit analysis of C&D waste management practices has been thought of as highly important to determine whether best practice techniques are cost effective, and is often necessary to provide incentive for reducing environmental impacts [16]. Typically, benefits are derived from the sale of salvaged waste materials, avoidance of landfill charges and lower cost of waste removal from site (either form salvage or direct reuse/recycle) [16, 49, 50]. Major cost categories often include labour, disposal costs, machinery use and transportation [16, 49, 50].

Most international studies focus on the financial and economic feasibility of recycling plants, rather than the feasibility of best practice demolition and onsite crushing activity [4]. It has also been suggested that economic analysis emphasises money, instead of the interaction between economic benefits and environmental impacts [44]. Some studies have therefore integrated a unit of cost per environmental impact into economic analysis.

Environmental life cycle costing (ELCC) is an alternative method seldom used in literature for calculating the costs of C&D waste systems. Usually the ELCC is assessed in terms of perspective, which can include the perspective of a society, community, consumer or company [7]. This tool is often used as a complimentary tool to LCA in sustainability assessments, and uses LCI data and available software for calculations [51].

3.4 METHODS RESEARCH CONCLUSIONS

These literature review investigations determined that the most effective data collection method was onsite data collection (instead of data collected through estimation), and the collection of data should depend on the objectives of the study. Data collection of specific objectives has been chosen as follows, with methods further described in detail in the Methods section:

1. *Gain an understanding of current issues or innovations within the C&D waste sector:* Semi-structured interviews and observations from site visits to waste facilities to facilitate case study research.

2. *Identify the waste contribution of the HSHS demolition to the WA waste stream and stockpiling, and if this could be further improved:* Primary data collection onsite via tip receipt collation of all wastes leaving the site, surveying stockpiles and counting waste quantities.

3. *Determine the environmental impacts of conducting a demolition using WA best practice:* Primary data collection of waste quantities, fuel, and energy onsite, supplemented by secondary data collection of emissions factors for environmental impact analysis via carbon footprint calculation.

4. *Determine the economic viability of conducting best practice demolition in WA:* Primary cost data from Merit and Landcorp collected across the entire demolition for a cost benefit calculation.

4 METHODS

This research is predominantly a case study of the HSHS demolition process and associated materials recycling. Rowley (2002) investigates the work of various important case study textbooks (including Robert Yin, often thought of to be the father of case study methodology) to summarise the key principles in case study methodology. Of this work, it was highlighted that case studies involving only one subject (such as the HSHS case) should only be chosen if there were unique or special aspects of the singular case [52]. In the HSHS demolition case study, the unicity lies in the demolition method (source separation), and subsequent future use of C&D material directly onsite being regarded as current WA best practice. It is believed that a recent commercial demolition of this scale and the previously mentioned unique aspects in a close residential setting has not been studied in WA yet, and thus represents a "special" best practice case appropriate for studying and to act as an example for future projects aiming to achieve similar results. Comparison to a BAU case will help to show measured achievements of this demolition.

4.1 INDUSTRY SURVEY

This section will specifically address Objective 1 of this thesis, and will also inform problem/improvement suggestions in other objectives. Industry insight has been gained via a series of site visits and semi-structured interviews with stakeholders to answer to the lack of social input in C&D waste management studies, and to identify current opinions and problems surrounding the WA C&D waste sector [41]. These interviews gathered information regarding current practices in the C&D waste industry, important viewpoints and identified any potential problems and barriers to a higher C&D recycle/reuse/recovery rate in WA. Results are presented in Section 0.

Interview questions were formulated keeping the aim and objectives of this thesis in consideration, along with Waste Strategy 2030 objectives. "W-Questions" were prioritised where possible, with the main questions being descriptive questions, and clarification of answers taking the form of explanatory questions [53].

It should be noted that no single viewpoint or opinion should be representative of their respective practices or areas of involvement. The study size is too small to be considered a scientific study, or representative of larger group viewpoints. In addition, at the time of question creation the WA Waste Strategy 2030 had not been released yet, and thus the questions were based on the draft waste strategy which was available.

4.2 SCENARIO ANALYSIS

Various studies devised different scenarios which were compared to their case study, and found to be effective in demonstrating how the case study performed against a BAU case [46, 54]. To measure the effectiveness of this demolition it was therefore necessary to compare the best practice techniques at HSHS to a BAU case. In addition to this, a worst-case scenario (WCS) comparison case was also added after interviews with stakeholders identified illegal practices which could negatively impact the environment. The main scenario features include:

- BAU: The normal demolition practices currently being used in WA, featuring comingled waste generation with some metal separation due to economic profitability. All wastes transported offsite with no direct reuse/recycle of materials. Faster timeline than HSHS.

- WCS: Comingled waste generated onsite is all sent to regional disposal facilities to avoid paying the landfill levy applied to Perth Metro areas. Very fast timeline.

These cases were created based on the practices identified in stakeholder interviews, literature research, and correspondence with the demolition team who could provide informed estimations based on their own experience in the C&D industry. Table A 6 and Table A 7 in the Appendix show specific descriptions and how each scenario changes from the HSHS case study in environmental and economic calculations

4.3 MATERIALS QUANTIFICATION AND DEMOLITION PROCESS

This method specifically answers to objective 2 of this thesis, however the process will also make up the primary data needed for other results and objectives. Materials have been quantified via collection of tip receipts, estimations provided by the demolition crew, weigh-cell use attached to loaders for stockpile mass and surveys of stockpiles. The destination of all materials has been summarised in Table 1 below, to show where each category of waste will end up after demolition. Recycled percentages are assumed to be total of generated waste, with no amount waste due to inefficient processing offsite. Processing efficiency could be further studied to gain knowledge on actual recycled percentages achieved in real-world applications.

TABLE 1 DESTINATION OF ALL WASTES GENERATED ONSITE

Material	Direct reuse	Direct recycle	Offsite recycle	Not recycled/ reused
Steel/metals	x		x	
Mixed brick/concrete		x		

Brick - cleaned	x			
Timber	x		x	
General waste			x	x
Greenwaste				x
Asbestos and contaminated material				x
Misc. salvage	x			

All waste quantification data is compared in units of mass (tonnes), and where this is not available from primary data, density data has been applied for conversions. This density data is a combination of primary density data gathered onsite, and secondary data from standard Western Australian Waste Authority and national density tables. Table A 8 and Table A 9 in the Appendix show the secondary density data. Table A 10 shows primary density data gathered onsite.

The demolition method was observed during bi-weekly meetings and conversations with the demolition team, including personnel from Merit, Tabec and Landcorp. The main observations were gathered concerning:

- How the demolition took place,
- The demolition timeline,
- Any problems which could be further streamlined for future projects
- Anything which sets this demolition apart from the business usual approach
- The process of achieving approval for onsite crushing activity

4.3.1 SCOPE AND LIMITATIONS OF MATERIAL QUANTIFICATION

All material quantities demolished at the HSHS site have been recorded by the onsite Merit demolition team, excluding density measurements, which were collected onsite and combined with online available data (as specified in the Appendix). The vast quantity of waste generated onsite meant that direct, daily onsite measurements were not possible, and as such the reliability of the data is dependent on the data collection facilities and demolition team. Raw data has been diligent analysed for inconsistencies, and clarification sought where any have arisen. No significant inconsistencies in data collection were evident throughout.

. The materials are separated during the demolition process, with quantities of each recorded after separation. The major material categories generated on site include:

- Steel/metals – including copper, aluminium, steel, stainless steel and brass. Taken from concrete supports, furnishings, piping and wire
- Bricks – Different kinds of bricks have been used throughout the construction of this school. Bricks which are solid have been cleaned for reuse in construction of a noise wall (proposed to be adjacent to Stock Road), and bricks which have holes in them are available for crushing (as the holes may compromise future structural integrity)
- Concrete – A large quantity of concrete has been used as the main material for construction of this school, used for structural supports, walls, building pads. This is to be crushed
- Mixed brick and concrete – predominantly consisting of concrete and brick, this also may include some tiles, glass, bitumen and other masonry materials. Two sizes of crushed material are produced, 50mm aggregate for use as drainage material and 20mm road base for use in future road construction

- **Timber** – taken from roof supports, flooring (gym), benches and some furniture. A large quantity of this is high quality treated jarrah, in which a small proportion has been kept onsite for direct reuse in POS areas

- **Greenwaste** - Any vegetation which could not be mulched for recycling or relocated, usually including bushes, shrubs or weed plants

- **Asbestos materials** – Contaminated material including roofing material, insulation, ANZ, piping

- **Asbestos concrete** – derived from concrete gutters, roofing and concrete coated with asbestos from building B (Figure 1).

- **Contaminated soils** – soils contaminated with asbestos from old construction activities during the school construction. To be disposed of at a suitable facility along with all other contaminated material.

Limitations to material quantification includes the smaller group of "materials for retention", which were mostly aesthetic objects. As this group of materials varies greatly in quality, density (depending on the object) and base material (E.G. wood from the sculpture tree or canvas from student artwork), and only makes up a small proportion of quantified material it has been excluded from analysis.

4.4 EFFECT ON CARBON EMISSION ANALYSIS

The goal of this environmental analysis is to answer to objective number 3 (Section 1.2), and will be performed to measure the environmental impacts of this demolition compared to BAU demolition techniques and WCS. The most important impact assessment category as identified in the literature review is climate change resulting from greenhouse gas emissions derived from human activities, as it is a critical issue for society and is the most commonly assessed impact category [43, 42].

4.4.1 METHOD DETERMINATION

It was determined through literature review that LCA was the most widely used and preferred method of environmental impact assessment for C&D activity on buildings, and as such it was considered for use in this environmental impact assessment. A more in-depth analysis of LCA techniques, however, determined that a traditional LCA is often too complicated for smaller applications [46]. In addition to this, the relatively short timeline in comparison to the length of a standard LCA both determined that the standard LCA process was unsuitable for this environmental impact analysis. As such the chosen method will be a carbon footprint of the demolition activity and direct reuse/recycle of wastes generated onsite, most like an end of life (EOL) LCA.

The carbon footprint calculation will utilise both primary and secondary data to calculate the GHG emissions from the HSHS site, presented in tonnes of CO_2-e across different scopes. The scopes are defined as:

- Scope 1 emissions – direct emissions usually derived from direct activity onsite and the resulting fuel burned

- Scope 2 emissions – indirect emissions derived from the use of energy onsite, from the offsite power generation
- Scope 3 emissions – indirect emissions derived from the extraction or production processes of fuels and materials and transport

[55]

Through the comparison between BAU and HSHS scenarios, the saving of avoided transport and avoided raw material use can be measured for the best practice techniques.

4.4.2 SCOPE, LIMITATIONS AND BOUNDARY

The environmental analysis is compromised of the demolition activity, associated recycling activity on the HSHS site, and avoided virgin material use resulting from recycling. This specifically includes:

- Demolition activity – measuring fuel use of all large machinery, along with energy consumption from power bills (scope 1 and 3 emissions of the fuel burned, scope 2 from energy consumption)
- Recycling of materials onsite – fuel use derived from crushing activities (scope 1 and 3 emissions of fuel burned)
- Transport of materials from the demolition site to processing facilities or disposal – distances calculated and associated fuel use estimated from this calculation (scope 1 and 3 emissions of fuel burned)

- Avoided raw material use – quantities derived from onsite data collection, and emissions saved from the use of directly recycled materials (scope 3 emissions saved)

Out of scope of this analysis includes:

- Operational activity of the building during use – The comparison of scenarios and recycle of C&D waste generated will have the same operational activity impacts, as this stage has not been altered for either scenario. Primary data for this section is also unavailable.

- Impacts from future construction activity (machinery use), or future maintenance stages – Primary data is unavailable, and the maintenance of road construction has already been studied in a research paper using a WA case study. This data will also be the same for all scenarios and will not affect comparisons.

- Specific activities which occur offsite to process waste generated at HSHS, including landfill activity and processing of wastes (however it should be noted that in the case of recycled metal use compared to virgin metal use, emissions factors have been used which account for offsite processing of recycled products.)

Figure 2 shows the system boundary, and associated calculation category for environmental impact assessment.

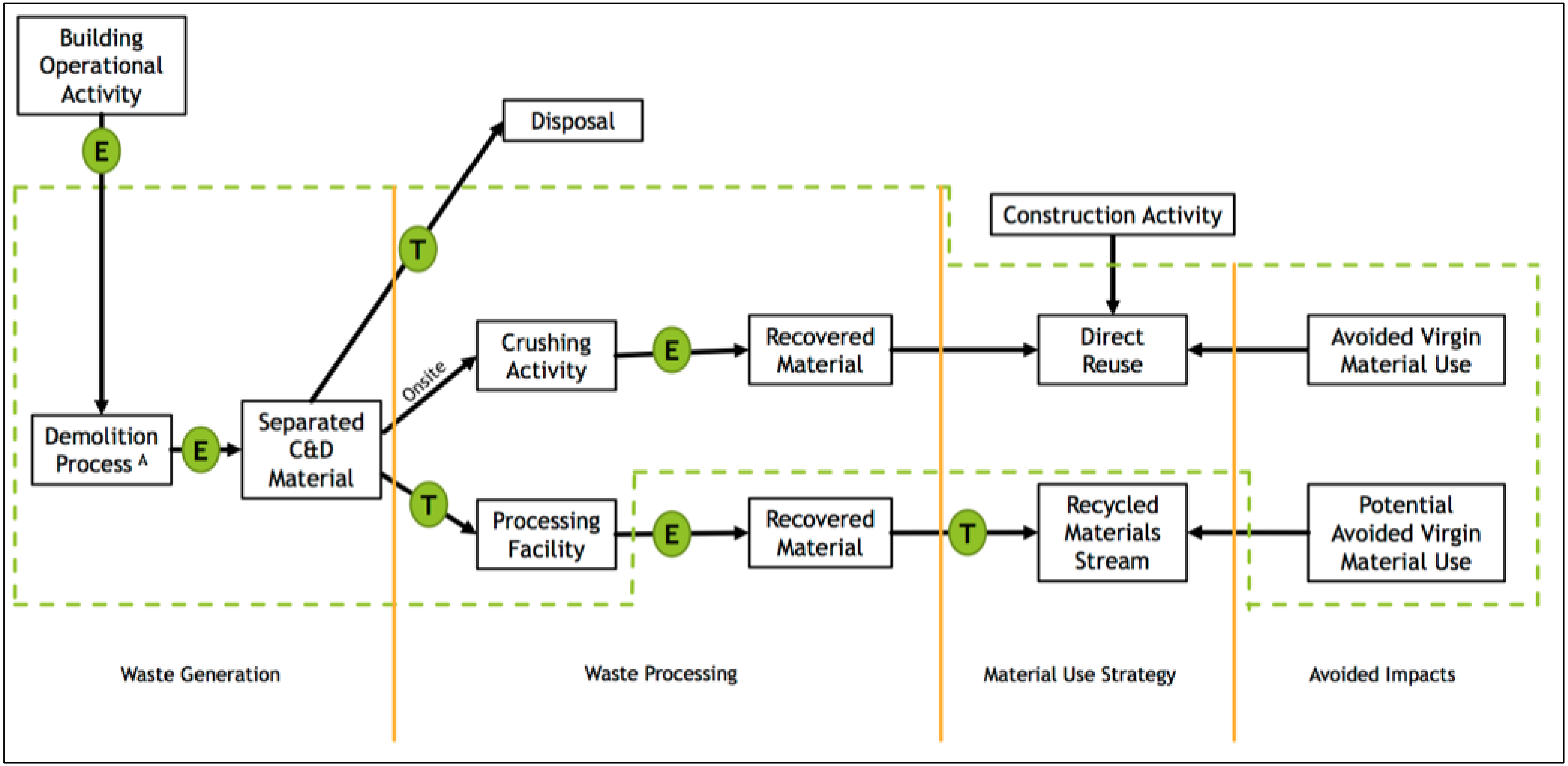


FIGURE 2 SYSTEM BOUNDARY OF ENVIRONMENTAL IMPACT ASSESSMENT

"E" – Emissions derived from machinery use *"T"- Emissions derived from transport of materials*

Source: created by author.

Table 2 summarises the category of GHG emission for the carbon footprint calculation, and the primary and secondary data necessary.

TABLE 2 DATA COLLECTION FOR CARBON ANALYSIS

Sub-category	Description for environmental assessment	Primary data	Secondary data
Transport	Transport of C&D waste from the site to various facilities (disposal, MRF or transfer stations)	Distance, fuel consumption,	Fuel use per km, CO2-e emissions factors (Scope 1)
Waste Generation	Machinery activity from demolition activity and separation of material onsite	Fuel consumption Power bills	CO2-e emissions factors (Scope 1, and 3) CO2-e emissions factors (Scope 2)
Waste Processing	Machinery activity from onsite processing	Fuel consumption	CO2-e emissions factors (Scope 1 and 3)
Avoided Impacts	Avoided impacts from not using virgin materials (from quantities informed by primary data collection onsite)	Waste quantities	CO2-e emissions factors (Scope 3)

4.4.3 CO_2-E CALCULATIONS

4.4.3.1 CALCULATION METHOD

Calculations were based on the equations outlined in the National Greenhouse and Energy Reporting (Measurement) Determination, which the methods and criteria are provided under the National Greenhouse and Energy Reporting Act 2007 (NGER Act) [56]. Where the calculation of avoided GHG emissions derived from avoiding raw material use was needed, these calculations were combined with those described in the Greenhouse Gas Assessment Workbook for Road Projects (TAGG 2013), which is the workbook available from WA Main Roads for GHG assessment of their road projects (with permission of use) [57].

4.4.3.2 EMISSION FACTORS AND UNITS

Calculations of GHG emissions were presented in CO_2-e tonnes. Emissions factors used in calculations were chosen based on applicability to this case study in terms of location and scope. Table A 11 in the Appendix shows a full list of considered emissions factors, with actual used factors highlighted. A combination of factors from the Australian National Greenhouse Accounts (for all fuel usage calculations), and WA Main Roads workbooks (for avoided material use) were determined to be the best fit for this study.

4.5 ECONOMIC ANALYSIS

Review of literature determined that an ELCC was too extensive of an analysis for this application, likened to LCA for an environmental analysis. A such, a cost –benefit analysis was conducted. Table A 7 shows how the BAU and WCS cases were created for economic analysis comparison.

The major cost and benefit categories were informed by literature review and an analysis of the major cost/benefit headings generated directly from this demolition.

4.5.1 SCOPE AND LIMITATIONS

Costs were calculated under the following headings:

- Labour – Broken down into brick cleaning, security and all other labour (approximately 4 to 5 workers on average for the strip out, approximately one week per building wing)
- Machinery use – Broken down into security items, repairs, machinery hire, crushing equipment, sea container application (noise suppression during crushing), equipment hire, environmental services.
- Fuel – Transport, onsite subcontractor fuel, machinery use
- Waste fees and enviro services – Contaminated waste, mixed waste and contaminated waste services
- Misc. Smaller costs – these included small materials purchased, lab testing and consultation fees, and safety costs

These represent negative values in the cost calculations, and are effected by the demolition timeline. A full description and breakdown of these costs will be provided in the appendix.

The benefits represent positive inputs into the economic analysis calculations, and were derived from:

- Salvage – Timber, metals, misc. items

- Avoided materials purchase – 50mm drainage material, 20mm road base, clean brick (including the cost to transport these materials)

In addition to the cost and benefit calculations, the scenario comparisons will also be represented in terms of cost per tonne of CO_2-e abated (or emitted). It was determined from literature that representation of environmental impacts and economic assessment in this way is beneficial to show the relationship between the two [44].

This analysis was limited by just the demolition activity onsite, and relative transport and waste disposal costs. It does not include the capital costs of the demolition equipment (as this would be the same for each compared case anyway), or the offsite waste processing costs from different recycling facilities.

5 RESULTS

It should be noted that the following results sections only display the results, with analysis presented in the subsequent Section 6.

5.1 INDUSTRY SURVEY

The viewpoints and information gathered during the semi-structured interviews were varied. Full transcription of specific answers is given in the Appendix – Interview Transcriptions. Table 3 below displays the most important answers to each question.

TABLE 3 RESULTS GATHERED FROM STAKEHOLDER INTERVIEWS

Question	General Answer
What are the major problems in the C&D waste industry of WA?	1. The cost of testing requirements required by main roads is thought of to be too high, and the testing regime too strict (found by two main stakeholders, however one stakeholder disagreed) 2. Smaller companies operating illegally without licenses could present a problem, as waste management at these facilities is not as monitored or regulated with licensing requirements. Illegal transport of waste to regional areas is also a problem, however not a newly observed one 3. Illegal transport of waste to regional areas (resulting from improper implementation of the landfill levy, and under regulated transfer stations) a big problem which needs to be dealt with 4. DWER testing and controls are too strict for processing facilities 5. Illegal dumping is a problem for regional areas 6. Lack of market leads to slow movement of some recycled wastes

What are the major solutions to these problems?	1. Robust accreditation and quality assurance measures help to improve recycled product quality, and opinion surrounding the product quality 2. More work needs to take place around regulation to improve C&D waste reuse and recycle 3. New draft Waste Strategy 2030 focus on CE step in the right direction
Is market development a barrier to greater C&D waste recycle in WA?	1. Market development is necessary, especially if extra testing requirements are needed to increase C&D material recycle and quality assurance to increase public perception of C&D products
Would new products be beneficial in market development?	1. Recycled concrete being reformed into concrete, can use fly-ash to replace the virgin component you need to reform it back into concrete. 2. Seawalls (good for the predicted sea level rise resulting from climate change) constructed with Nano-hydrocarbons in concrete curing, so the reinforcing steel is not needed. Usually the steel can cause these sea walls to break, so this is a significant innovation which will also reduce raw material use. 3. Suggested that recycled road base is the most important material to encourage higher C&D waste recycling, not newer products to increase demand
What key waste quantities generated from C&D activity not accounted for in the recycling stream? How/why?	1. Plastics, medium-density fireboard (MDF) and resin-treated wood are problems as they cannot be recycled and often contaminate otherwise separated, recyclable waste. Finding ways to deal with these proportions (such as waste to energy) would further enhance circular economy efforts

Findings are discussed in Section 6.1.

5.2 DEMOLITION PROCESS AND TIMELINE

Prior to bulk demolition works, Landcorp did consider the reuse of whole buildings, however safety concerns due to the age and quality of construction did not result in this option, and instead best practice demolition techniques were used instead of building reuse. The demolition process has been summarised in Figure 3 below. The most important aspects of this best practice process included:

- Salvage of any furniture, aesthetic features for future construction (valuable items secured in sea containers), or any material able to be used in nearby sites (for example, part of the gym framework to be directly reused and salvaged for the nearby East Village construction also by Landcorp)

- Separation of different waste materials, including major categories of timber, metals, concrete, brick, vegetation ("greenwaste", mulch or relocated vegetation) and contaminated materials. This process was best described by the demolition team and Landcorp as a deconstruction rather than a demolition, which is often the term used for best practice techniques. The separation and removal of floors and windows is usually via machinery, however in this project labour was used due to extra asbestos contamination. Additional timber floorboards separated using floor lifters, and extensive metal removal for salvage (via picker processes during demolition, pulverising and crushing) resulted in a longer timeline and more labour for this activity. In general, more labour and an extended demolition timeline was needed for most material separation

- Bulk demolition was conducted by three excavators, one 36t with a pulveriser attachment for pre-crushing concrete, and two other 20t. Attachments used include rake bucket, grapple, rock breaker and GP bucket. Smaller machinery was also used for aid in stockpiling. Some copper and brass were cut away from less valuable metals onsite to increase salvage value. Metal support steel (also termed “reo”, or reinforcement bars) in concrete was also picked out via machinery after pulverisation.

- Strict security and safety requirements were evident throughout demolition
- Ongoing public consultation, including the acknowledgement of any complaints. Complaints were often regarding the loss of vegetation because of demolition activity, or lack of understanding from the surrounding community about the sustainability initiatives of the demolition.
- Added social benefits gained from allowing firefighting and disaster training occurred onsite prior to demolition which adds value to the demolition for training purposes
- Onsite crushing, brick cleaning and mulching allowing for the direct recycle of waste materials generated onsite

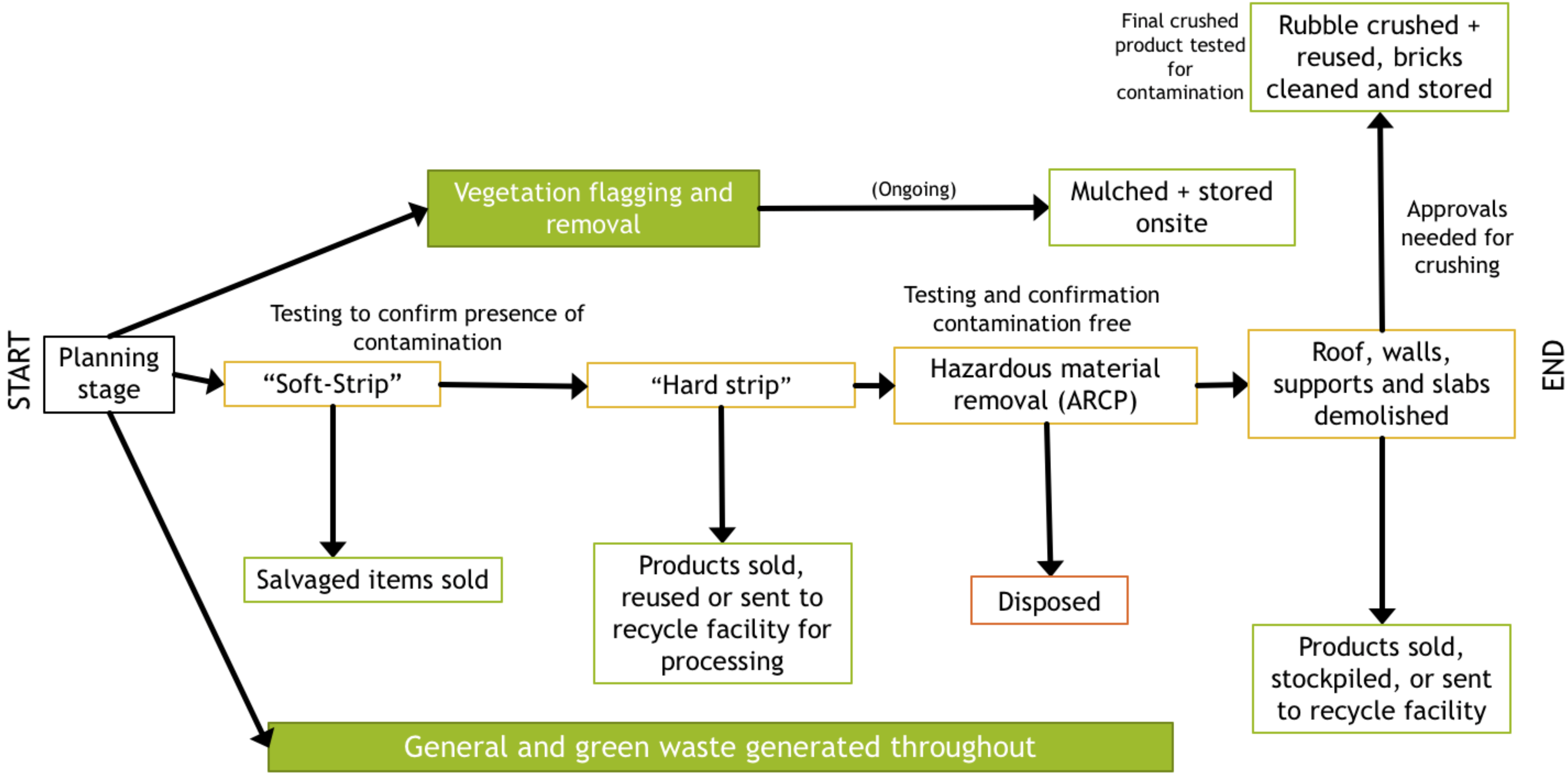


FIGURE 3 DEMOLITION PROCESS

Note: Soft strip – internal furniture and carpets *Hard strip – Glass, window frames, suspended ceilings*

Source: Author.

5.2.1 ASBESTOS CONTAMINATION

As the HSHS buildings are quite old, the use of asbestos in its construction was prevalent. The onsite crushing activity meant that asbestos removal was a high priority for this demolition process (due to license and contamination requirements form DWER), and as such the removal of contaminated materials was extensive to create high quality, recyclable crushed material. Small amounts of contamination of one stockpile would mean that the entire stockpile would need to be disposed of, and generate large quantities of waste sent for disposal. As such, a detailed Asbestos Removal Control Plan (ARCP) (Merit, 2018) was implemented onsite, and was successful in preventing the contamination of clean material. The specific process required to ensure no contamination of recyclable crushing material involved:

- Dust monitoring (suppression with a 14,000L water truck and a series of water sprayers and blowers);
- Verification of asbestos removal from buildings and offsite (ANZ, Aurora and GHD involved in this process). GHD needed to be confident in the process of demolition that crushed material will be contamination free, as well as the crushing activity.
- Airborne asbestos monitoring during demolition and crushing – using 4 asbestos monitoring devices, locations determined each day with filter testing overnight at a NATA accredited laboratory
- “Emu picking”, which is essentially the practice of visual inspections carried out during demolition to identify asbestos which may have been undetected

- Strategic stockpiling to mitigate the risk of losing entire quantities of crushed material in the event of contamination
- Visual inspection of materials prior to crushing as per guidelines [58]
- Visual inspection of resulting crushed 50mm material as per guidelines [58]
- Sampling and testing of 20mm crushed material in accordance with the Department of Health guidelines

5.2.2 PROBLEMS AND SET-BACK OBSERVATIONS

Throughout the demolition, set-backs were experienced from latent contaminated material finds which pushed the entire demolition project back. Latent finds of Asbestos Contaminated Materials (ACM) occurred later into the project timeline than expected due to the success of the ARCP (which is a good result for asbestos removal, but not for demolition timeline). Further testing and sign-offs were required due to this, which pushed back the bulk demolition works that could only proceed after approval was received to keep the waste uncontaminated for crushing. Delays from an expected 54 days for asbestos removal, pushed to 188.5 (134.5 days of delay). The knock-on effect has cost implications further discussed in the results interpretation section.

In addition to this, the approvals process for the crushing license took longer than expected. This was due to the strict noise suppression, local government approval and strict asbestos removal requirements which were required by DWER. Specifically, comments made on the application for the license included:

- Confirmation of noise barrier height (using sea containers), in which acoustic modelling was required to confirm the noise emissions made to the surrounding residential areas
- Noise complaint action plan was required if surrounding residents complained (no complaints were received throughout the crushing process)
- Verification of asbestos removal of crushing material was required

These changes, in addition to the length of time taken to grant approval meant that the total crushing process with approvals took 163 days instead of the expected 74 days. The approvals process was 51 days longer than the expected 60 days.

Some social problems arose during demolition, mainly regarding the removal of vegetation onsite to which painted signs were attached to fencing surrounding the site voicing the problems. Some surrounding residents observed the removal of native trees which was complained about, however communication of tree retention and relocation with protestors discouraged further behaviour. Fifteen complaints were made regarding the demolition works, all of which were resolved and due to the reasons previously mentioned.

Illegal dumping onsite was observed, of wrapped asbestos and tyres. This waste was disposed of appropriately by the demolition team along with other contaminated waste. The sale of timber was also a difficult process, as most suppliers only wanted clean, stacked timber. Some timber was sent off as firewood for free.

Some aspects of the demolition were based on trial and error. An example of this is the salvage of the breezeblocks, in which half of the expected salvage quantity was crushed (destroyed for originally intended reuse purposes) due to the removal technique and age of the material.

5.3 MATERIALS QUANTIFICATION

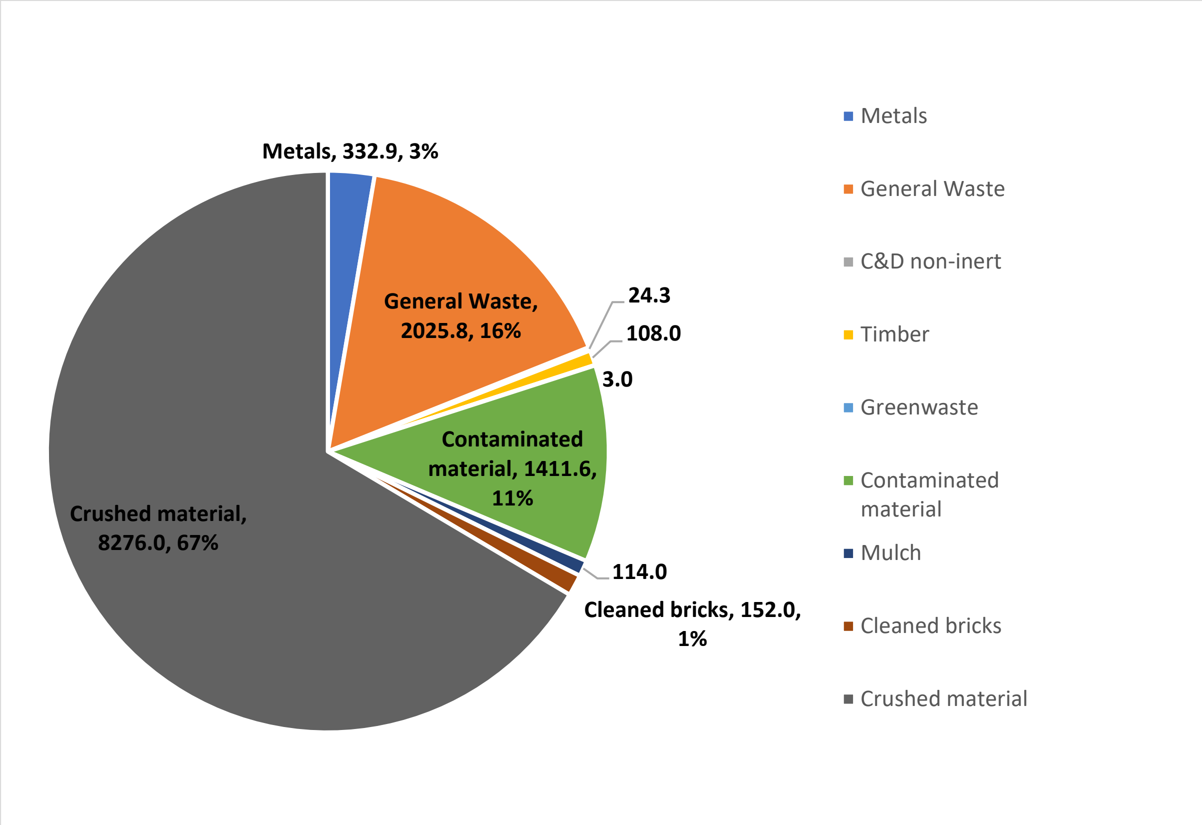
Table 4 below shows quantities of all wastes generated onsite. These results have been gathered using methods described in the Methods section. Table A 12 and Table A 13 in the Appendix show a breakdown of each heading and associated density calculations.

TABLE 4 SUMMARY OF ALL WASTES GENERATED ONSITE

Material	Mass (t)	Percentage of total	Recyclable/ Reusable material (t)	Actual Amount Reused/Recycled (t)	Percentage of material Reused/ Recycled
Metals	332.9	2.7%	332.9	332.9	100.0%
General Waste	2025.8	16.3%	2025.8	1215.5	60.0%
C&D non-inert	24.3	0.2%	24.3	24.3	100.0%
Timber	108.0	0.9%	108.0	108.0	100.0%
Greenwaste	3.0	0.0%	3.0	3.0	100.0%
Contaminated material	1411.6	11.3%	0.0	-	-
Mulch	114.0	0.9%	114.0	114.0	100.0%
Cleaned bricks	152.0	1.2%	152.0	152.0	100.0%
Crushed material	8276.0	66.5%	8276.0	8276.0	100.0%
TOTALS	**12447.5**	**100.0%**	**11036.0**	**10225.6**	**92.7%**

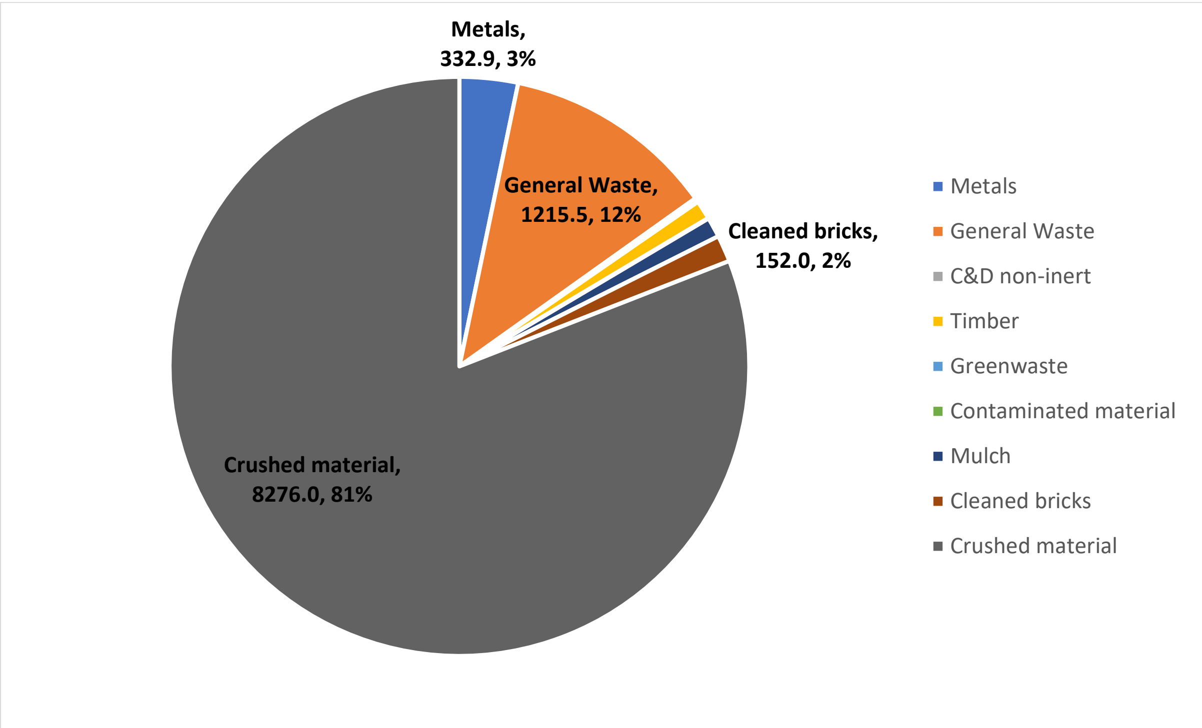
Note: The recycled percentages were derived from waste generation data from Merit, and are assumed to be correct to the best of the team's knowledge.

Figure 4 and Figure 5 below display the percentages of each waste category within the total waste generated onsite and the total recycled material onsite respectively.



(UNITS IN TONNES)

FIGURE 4 PERCENTAGES OF TOTAL MATERIALS GENERATED ONSITE



(UNITS IN TONNES)

FIGURE 5 PERCENTAGES OF RECYCLED MATERIALS GENERATED ONSITE

The BAU case comparison scenario would have 8650 tonnes of extra waste material to deal with due to the lack of onsite recycle and reuse. This equates the proportion of mixed waste for BAU to 11036 tonnes, and 1411 tonnes of contaminated material. WCS comparison would deal with these same quantities, as ACM is separated in all cases due to the high cost of disposal (higher than landfill levy payments) (see Table A 7 for a full description of different scenario derivations). 7369 tonnes of 20mm crushed material was generated for road base in road construction of the new development, and 907 tonnes of 50mm crushed material generated for drainage. Further discussion of results has been provided in Section 6.

5.4 CARBON ANALYSIS

Calculation of the greenhouse gas emissions for an environmental impact analysis involved calculating onsite fuel usage and transport distances and associated fuel usage (Scope 1 emissions). It was assumed that energy consumption and related GHG emissions were the same for all scenarios (scope 2 emissions). Table A 14 and Table A 15 show calculations for onsite fuel usage and transport fuel respectively. These fuel quantities were then used to calculate GHG emissions for each scenario, along with associated materials purchase and the implications of using raw resources using emissions factors, as shown in Table A 17, Table A 18 and Table A 19 respectively for HSHS, BAU and WCS. Specifically for the raw materials use section, the emissions predicted to be generated are derived from the production and extraction of the raw material (as per the description for Scope 3 emissions in Section 4.4).

Table 5 below displays the total GHG emissions generated from this demolition, and comparison to the BAU and WCS cases.

TABLE 5 GHG EMISSIONS

	HSHS (t CO2-e)	%	BAU (t CO2-e)	%	WCS (t CO2-e)	%
Machine Use	230.84	80.8%	151.88	79.7%	84.29	59.6%
Electricity	5.18	1.8%	5.18	2.7%	5.18	3.7%
Crushing Activity	35.68	12.5%	0	0.0%	0	0.0%
Transport	13.86	4.9%	33.45	17.6%	52.03	36.8%
Raw Material Use	0	0.0%	117.95	61.9%	117.9489	83.4%
TOTAL	**285.57**	**100.0%**	**308.47**	**100.0%**	**259.45**	**100.0%**

Table 6 below shows the GHG abatement achieved through direct reuse and recycle at HSHS compared to the BAU and WCS (see Table A 7 for a full description of different scenario derivations). Breakdowns, of these calculations are provided in Table A 17, Table A 18 and Table A 19 respectively for HSHS, BAU and WCS.

TABLE 6 GHG EMISSION ABATEMENT

Avoided Parameter	Quantity	HSHS abatement (t CO2-e)	Abatement/ tonne of waste	BAU (t CO2-e)	WCS (t CO2-e)
Transport to crushing	4.98 (kL)	-13.56	-2.72	0	0
Raw 50mm aggregate material	907 (t)	-6.35	-0.01	0	0
Raw 20mm sub-base	7369 (t)	-52.32	-0.01	0	0
Brick	152 (t)	-59.28	-0.39	0	0
Raw Aluminium	5.39 (t)	-102.52	-19.02	-91.371	0
Raw Steel	322 (t)	-364.70	-1.13	-294.016	0
Raw Copper	2.9 (t)	-14.82	-5.04	-14.822	0
TOTALS	8759.1	-613.54	-0.07	-400.21	0.00

Table 7 below displays the result of GHG emissions for each scenario. Green are abatement results, and red represents a net emission of GHG.

TABLE 7 NET GHG EMISSIONS

	HSHS	BAU	WCS
GHG Emission (t CO2-e)	-327.97	-91.74	259.45

The following figures show the percentages of GHG emissions under the major categories of generation.

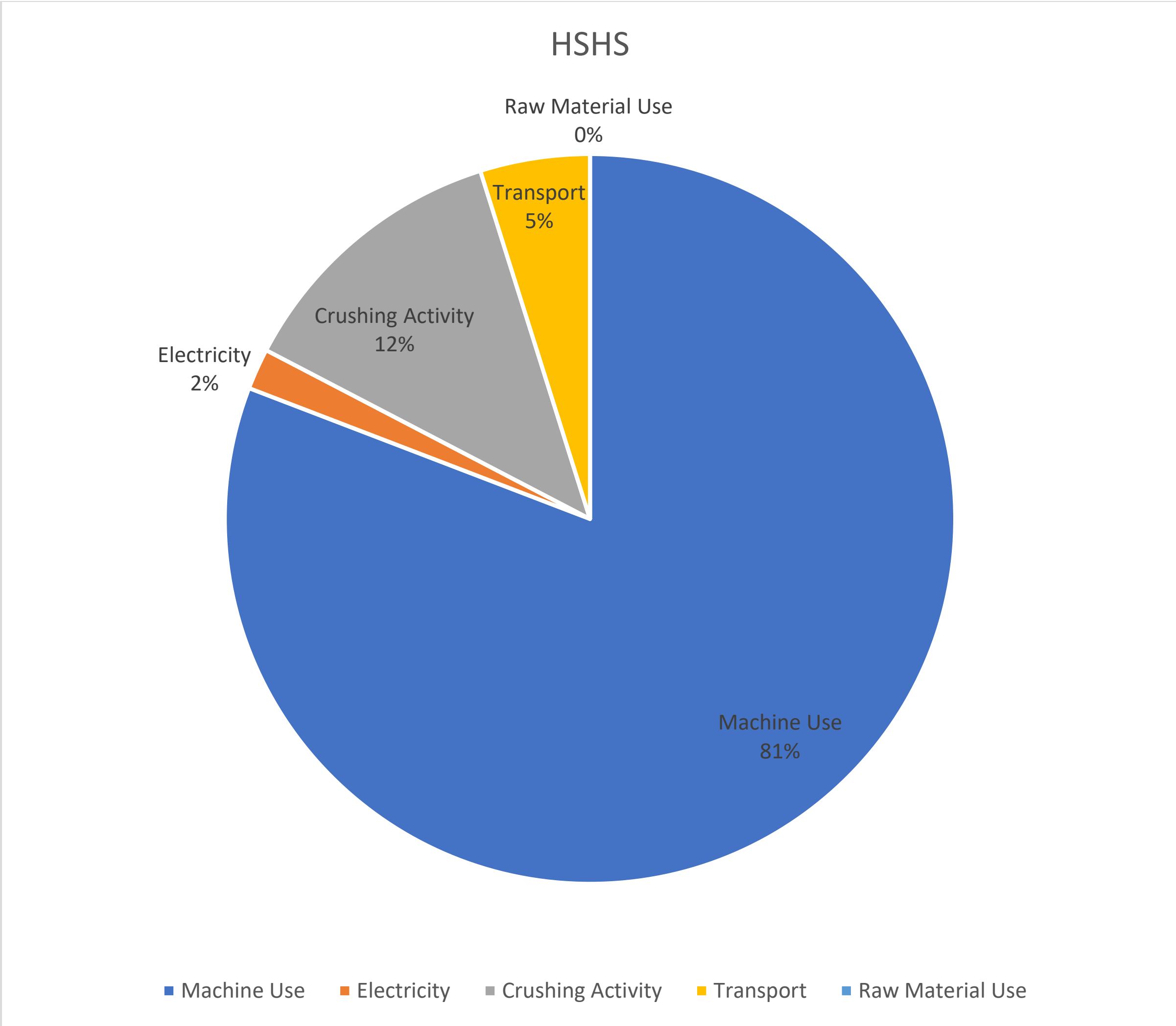


FIGURE 6 GHG EMISSIONS FROM HSHS

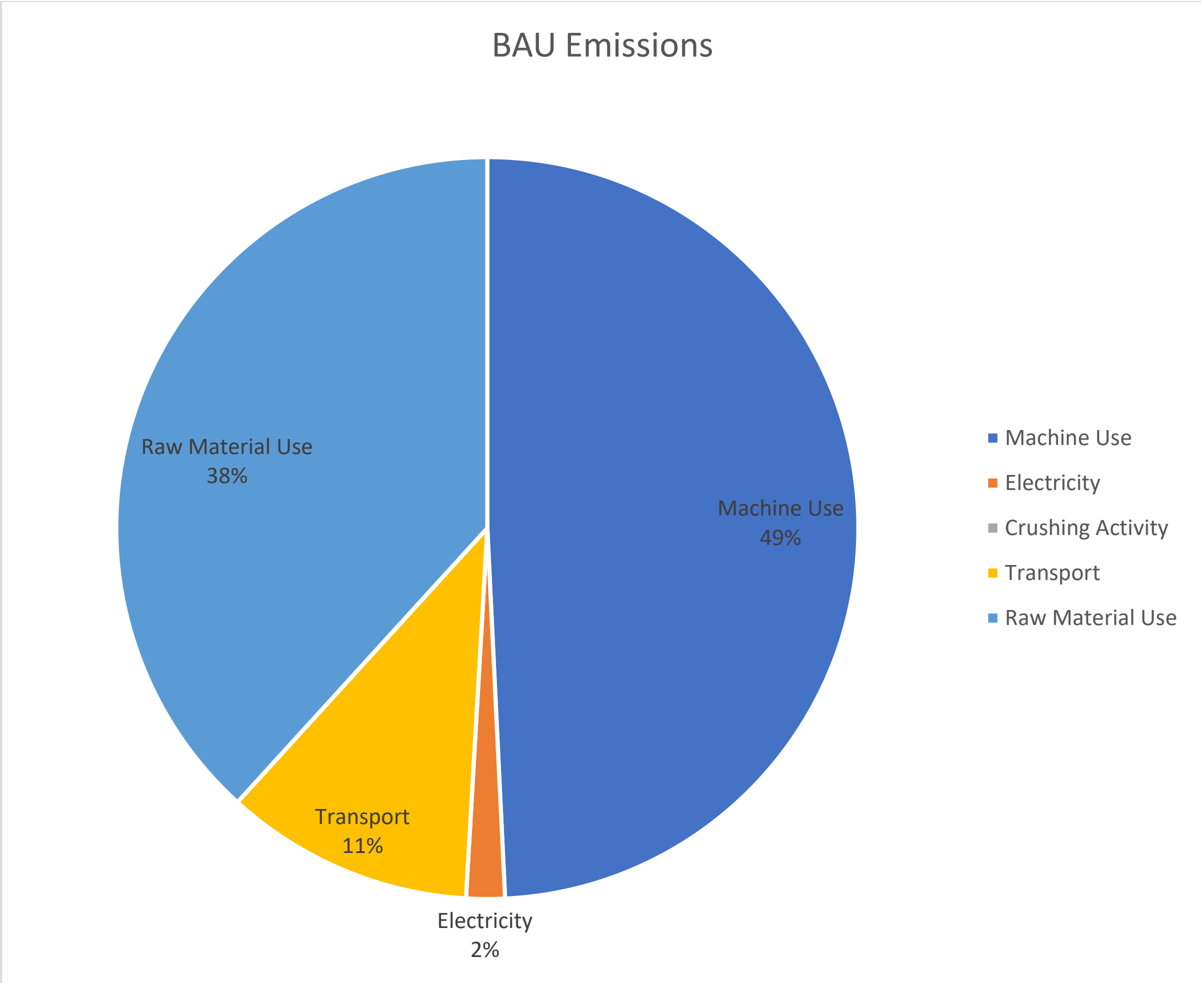


FIGURE 7 GHG EMISSIONS FROM BAU CASE

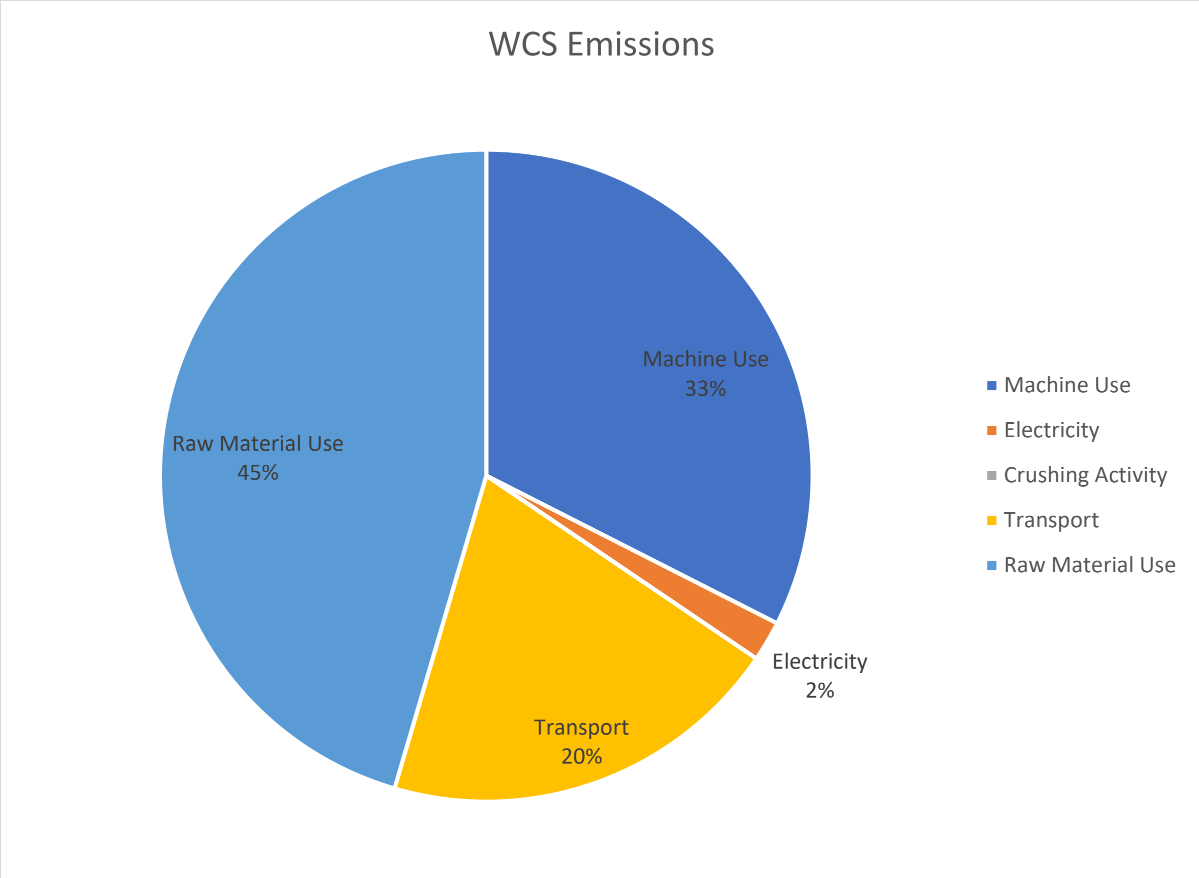


FIGURE 8 GHG EMISSIONS FROM WCS

Further discussion and analysis of results has been provided in Section 6

5.5 ECONOMIC ANALYSIS

Tables 8 to 10 below summarise the cost-benefit analysis of the demolition and scenarios. A breakdown of these costs is available in Table A 16, Table A 20, Table A 21, and Table A 22 in the Appendix. A breakdown of the benefits is provided in Table A 23.

TABLE 8 SUMMARY COSTS OF EACH SCENARIO

	HSHS	BAU	WCS
Labour	-$472,661.40	-$274,257.49	-$197,074.78
Machinery Use	-$615,654.37	-$30,713.67	-$70,915.80
Fuel	-$210,146.49	-$163,312.15	-$140,091.88
Waste Fees	-$613,782.30	-$1,140,093.09	-$801,378.19
Misc. Smaller Costs	-$57,942.35	-$55,777.35	-$52,414.10
TOTALS	**-$1,912,244.56**	**-$1,608,376.40**	**-$1,209,460.66**

TABLE 9 SUMMARY BENEFITS OF EACH SCENARIO

	HSHS	BAU	WCS
Salvage	$96,948.31	$74,995.48	$0.00
Avoided Materials Purchase	$155,847.00	$0.00	$0.00
TOTALS	**$252,795.31**	**$74,995.48**	**$0.00**

TABLE 10 COST OF EACH SCENARIO

	HSHS	BAU	WCS
Cost	-$1,970,186.91	-$1,777,068.99	-$1,417,721.76
Benefits	$252,795.31	$74,995.48	$0.00
TOTALS	**-$1,717,391.60**	**-$1,589,158.27**	**-$1,261,874.76**

The following figures summarise the costs for each scenario.

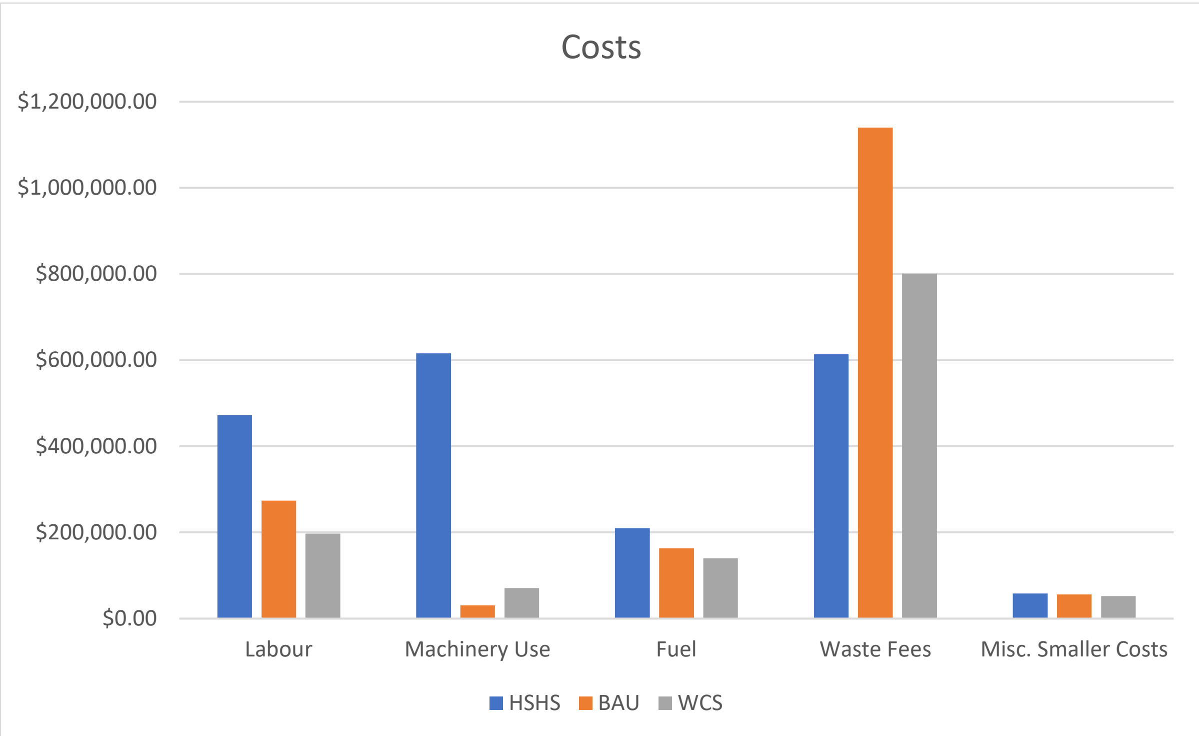


FIGURE 9 SUMMARY OF COSTS UNDER MAJOR HEADINGS

Figure 10 below displays the benefits derived from each scenario process. The breakdown of these calculations have been provided in Table A 23 of Appendix 3.

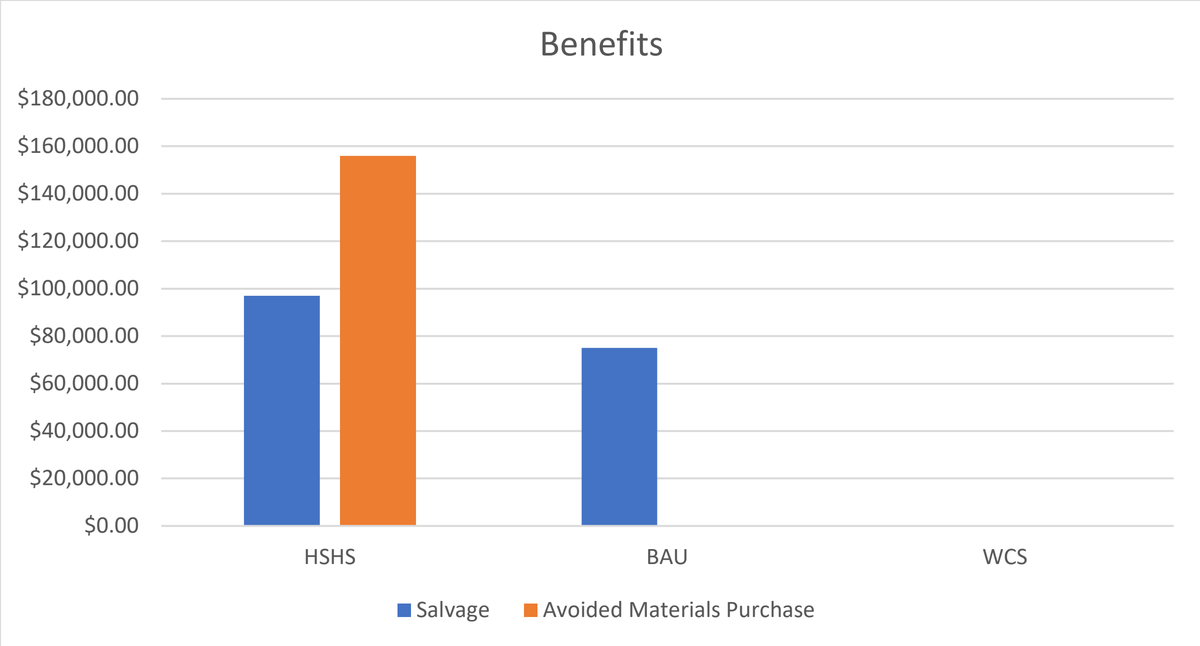


FIGURE 10 SUMMARY OF BENEFITS UNDER MAJOR HEADINGS

The following figures show the proportion of costs which each major heading accounts for.

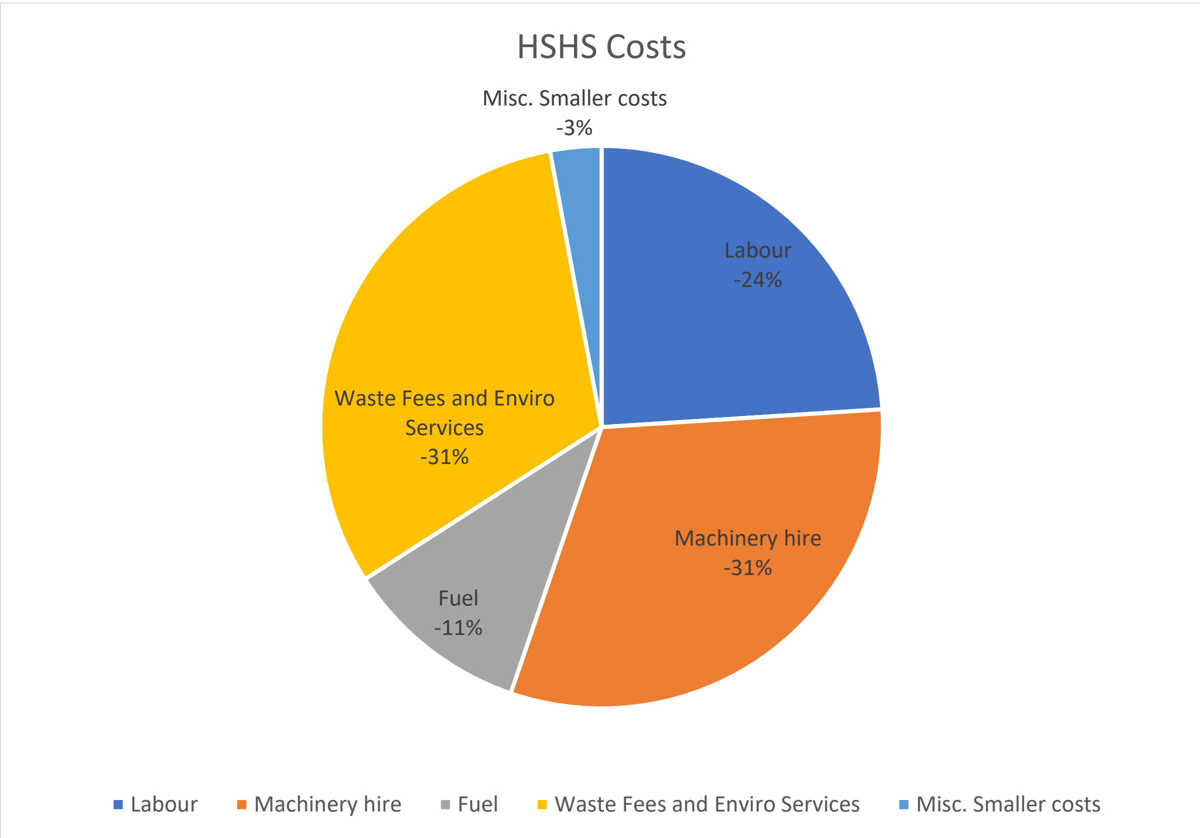


FIGURE 11 HSHS COST PROPORTIONS

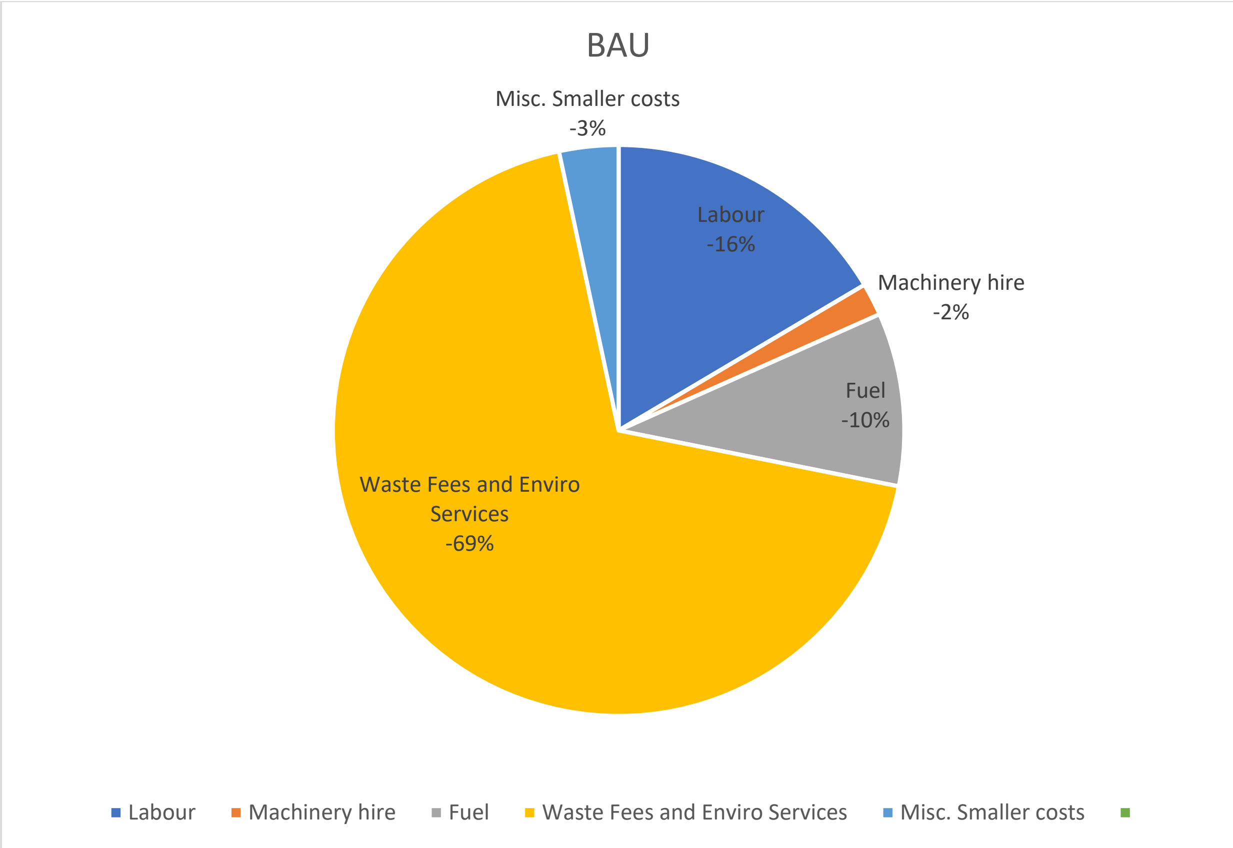


FIGURE 12 BAU COST PROPORTIONS

Further discussion and analysis of results has been provided in Section 6.

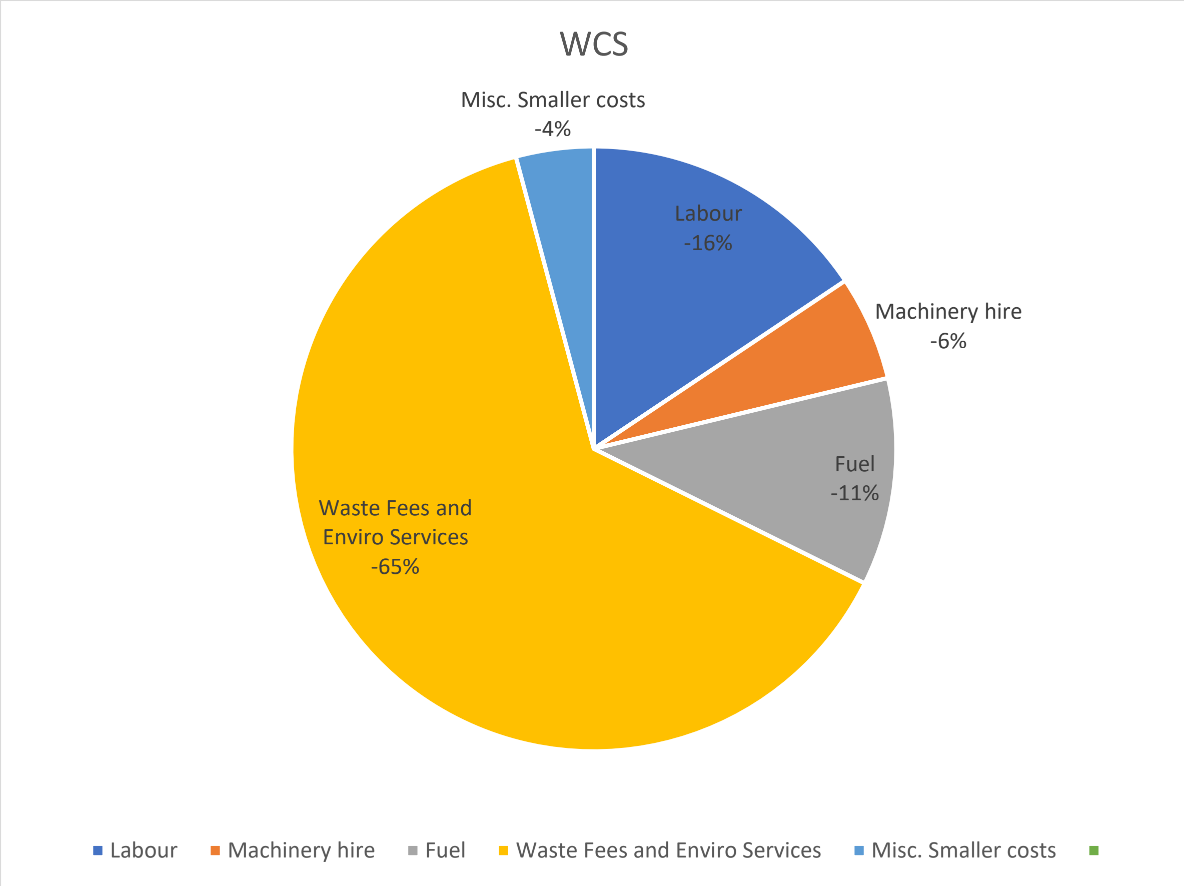


FIGURE 13 WCS COST PROPORTIONS

5.5.1 OBSERVATIONS:

- Approximately $240,000 worth of additional contamination finds increased costs
- Security costs increased because of extended timeline (from latent finds and crushing approvals)
- Each scenario would avoid approximately $715,000 of landfill levy payments (excluding ACM soils)

Further discussion and analysis of results has been provided in Section 6.

6 DISCUSSION AND INTERPRETATION

The results section is used to address the objectives in this section, and as such it is structured around answering to the specific objectives instead of interpretation of the results headings (although they are aligned).

6.1 OBJECTIVE 1

This section will discuss how the results have responded to objective 1, *"Gain an understanding of current issues or innovations within the C&D waste sector".* Industry Survey was the main method used to address this objective, however all results sections informed an understanding of issues and areas for innovation within the WA C&D waste sector, and specifically demolition practices. Table 3 results are discussed below.

6.1.1 ISSUES WITHIN THE C&D WASTE SECTOR OF WA

Industry survey identified that the testing requirements needed for the recycle of crushed C&D waste in road projects conducted by Main Roads could potentially be both too strict and costly to be viable. This may be the case, however as several stakeholders brought up the problems in the past with contamination leading to low opinion and low recycle rates of recycled C&D material it is also deemed as necessary. This problem is further evidenced in demolition timeline observations at HSHS, in which strict requirements for onsite crushing resulted in late approvals for onsite crushing, large setbacks for the demolition timeline and a knock-on effect increasing the demolition costs (further discussed under Objective 4). A possible solution to this could be to supplement the cost of testing requirements, which could increase economic feasibility and improve recycled C&D product recycle to Main Roads projects (and not just small scale development projects), and adoption of CE.

There were a variety of illegal practices evident in the industry, which can result in a loss of recyclable and valuable C&D material to disposal, and will hinder CE efforts. These practices were identified to be illegal dumping (regional), and the transport of waste from Perth metro areas to regional disposal for avoidance of high disposal costs associated with the landfill levy. The illegal transport to regional areas is enabled by poor regulation and implementation of the landfill levy. Voluntary waste reporting further allows this problem to occur. As evidenced by the comparison to WCS, this latter illegal practice is also often faster, cheaper and therefore easier for a demolition company to perform, and as such there is incentive for this practice to occur. One suggested solution to this is to increase the regulation on C&D waste reporting and put in place measures to accurately track or measure quantities with compulsory waste reporting. It was observed that one facility voluntarily used GPS tracking as assurance to their customers that their waste or delivery of recycled products is conducted in a sustainable way, and could act as an example for other facilities.

Materials such as MDF, plastics and resin-treated wood were identified by one stakeholder as C&D wastes which WA is unable to currently recycle, and represent a problem for transitioning to a CE. These materials can contaminate an otherwise "clean" waste stream, and make it difficult for processing facilities to improve the output quality of their recycled C&D products. The materials quantification results (Section 5.3) reflected that 7.3% of recyclable materials (810 tonnes) were estimated to be disposed of, and could consist of this kind of C&D material especially as MDF is often the material used in a large quantity of school furniture such as desks and shelves. To further improve the value gained from C&D wastes (in both an economic and environmental context, and possibly social context with the creation of jobs) one strategy to deal with this problem could be the provision waste to energy facilities used to generate energy for the local centralised electricity grid. This suggestion did originate from a stakeholder who is set to gain economic benefits from such a facility, however, and as such the solution to this unrecyclable C&D waste problem should be further investigated for benefits to the wider community.

6.1.2 MARKET DEVELOPMENT

Lack of market development for C&D products was identified early as a barrier to increasing the recycle and reuse of WA C&D waste, and this was confirmed to be an issue with many stakeholders. The low opinion of C&D waste was one of the issues with the current market, as this has often left recycled products undervalued. This has been evidenced in the HSHS demolition project, where timber salvaged onsite was hard to move, and a portion was sent away as free firewood. The highest quality jarrah and floorboards were easier to sell, and suggests this may have been an issue of quality. Enhancing quality assurance could therefore be an acceptable way to increase the market creation of C&D materials, either implemented at the demolition site or with processing facilities. Compared to products valued in other states of Australia, there is work to do to increase the perception and value of recycled C&D waste products in WA. The success of the current WA Main Roads trial of 25,000 tonnes of recycled C&D material used in road construction could help to improve the value of recycled crushed aggregate, and the result of this is suggested to be pivotal in shaping future crushed C&D waste recycling and transition towards a CE.

6.2 OBJECTIVE 2

This section will discuss how the results have responded to objective 2, *"Identify the waste contribution of the HSHS demolition to the WA waste stream and stockpiling, and if this could be further improved"*. The Material quantification section (Section 5.3) provided results to answer to this objective.

The largest proportions of materials generated were the crushed material (67%), general waste (16%), contaminated material (11%) and metals (3%). The high percentage of contaminated material is reflective of the age of the building, as asbestos use was still prevalent during the time of construction (Table 4 and Figure 4).

The contribution of waste directly to the C&D waste stream was determined to be recyclable waste which was not processed, recycled or reused onsite. This quantity consisted of greenwaste, C&D non-inert material and general waste, and totalled 2053.1 tonnes, or 16.5% of total waste generated. 1242.7 tonnes of this material were estimated to be recycled, with approximately 810 tonnes (40% of the general waste generated onsite added to greenwaste and C&D non-inert) disposed of and added to the landfill stream (Figure 5). The materials assumed to be added to existing stockpiles were 60% of the general waste (1242 tonnes) and 332.9 tonnes of metal salvaged accounting for 12.7% of total material generated onsite. Stockpiling of crushed material was not significantly contributed to with this demolition due to the large amount of onsite recycling.

A total of 92.7% of all recyclable waste (that is, not including contaminated waste) was recycled, achieving Landcorp's 90% goal. The major materials saved from entering the C&D waste stream due to direct reuse and recycle consist of the cleaned bricks, crushed material, timber salvaged, and mulch (153 t, 8726 t, 108 t, 114 t respectively) for a total of 8650 t, and accounting for 69% of total waste generated. The other percentage of waste consists of contaminated waste, accounting for 11.3% of the total waste generated onsite (see Figure 5), and when added to the portion of general waste not recycled this accounts for 17.8% of the total waste generated sent to disposal.

Direct reuse of material was only observed with cleaned bricks and aesthetic features (approximately 152 tonnes). Although recycle of waste can result in economic and environmental benefits, material circularity is an important consideration for transitioning to a circular economy. As identified by the literature review, design for deconstruction could help to improve material circularity.

To summarise, the contribution of HSHS waste to stockpiling activity and the C&D waste stream was low. With the increase of brownfield developments set to increase, innovation directed at reducing the amount of waste disposed of due to contamination could be beneficial if demolition of similar aged building occurs [59]. The strict ARCP and extensive measures to ensure unnecessary contamination of crushed material at the HSHS site leaves little room for improvement, with all stockpiled material passing testing requirements and remaining contamination free. The best practice measures used onsite are seen to be successful in the transition towards a CE because of this, with the current technology and legislative factors at play.

6.3 OBJECTIVE 3

This section will respond to Objective 3, *"Determine the environmental impacts/savings of conducting a demolition and potential construction using WA best practice"*. Comparison to a BAU and WCS allowed analysis into how this demolition impacted the environment in a GHG emission and climate change context. Low emissions for the HSHS demolition can help to provide incentive for future projects, and will support the transition of techniques working towards WA's CE transition.

6.3.1 PERFORMANCE

The HSHS demolition demonstrated the largest environmental impact savings out of all scenarios, with a net abatement of 327.97 tonnes of CO_2-e (tCO_2-e), followed by BAU with 91.74 tCO_2-e and WCS with net emissions of 259.45 tCO_2-e (Table 7). The machinery use accounts for the highest proportion of emissions for both HSHS and BAU, accounting for approximately 80% for HSHS, 49% for BAU and 33% of emissions for the WCS (see Figure 6, Figure 7 and Figure 8). WCS saw the highest proportion of predicted GHG emissions derived from raw material use (i.e., extraction and production of the raw materials) in Figure 8. The HSHS demolition avoided approximately 33 tCO_2-e in transport emissions through direct recycle and reuse. This was derived from not having to transport around 7000 tonnes of masonry material to crushing facilities, and avoiding the transport of material back onsite.

Transport emissions account for 20% of all emissions in the WCS, 11% for BAU and 5% for HSHS, which is a significant change from HSHS to the other scenarios (see Figure 6, Figure 7 and Figure 8) . This 20% from WCS represents a significant problem. In addition, the use of raw materials for both BAU and WCS cases also represents a significant problem, accounting for large amounts of total emissions (approximately 120 tCO_2-e for each scenario, see Table 5).

Benefits from avoiding raw material use and lowering transport emissions were high for the best practice HSHS case, and well evidenced in these emissions calculations of both GHG emission and abatement.

6.3.2 IMPROVEMENTS

Further environmental benefits can be made from using low emission machinery, as this accounts for a large amount of GHG emissions across all scenarios. The illegal practice of WCS shows large environmental impacts from the emissions it produces, and discouraging this practice via regulation and correct application of the landfill levy to regional areas could discourage this practice and avoid the harmful emissions.

Overall, this demolition displays high environmental impact savings (in the form of carbon savings in a climate change analysis) when compared to the BAU and WCS case, and the input of additional emissions from crushing activity is well accounted for in the avoidance of raw material use and associated GHG abatement. With an input of 35 tCO_2-e emissions, an abatement as large as of 613 tCO_2-e is achievable under the same conditions.

In terms of material circularity, direct reuse of steel structures could help to further reduce transport emissions and possibly labour and machinery emissions if structures are designed to be dismantled with ease [31]. The direct reuse of bricks did not need an input of GHG emissions (due to only labour needed to sort and clean the bricks, with fuel use only needed for transport of the pallets in both cases) and is an example of how reuse can often lead to net greater benefits than recycle. The benefit of brick reuse resulted in an abatement of 59 t CO_2-e, with zero input of greenhouse gas emissions like the crushing activity necessitates. Direct reuse of concrete supports or steel could further reduce the 265 t CO_2-e needed for crushing and demolition.

6.4 OBJECTIVE 4

This section will respond to Objective 4, *"Determine the economic viability of conducting best practice demolition in WA"*. Comparison to a BAU and WCS allowed analysis into how the best practice techniques performed in an economic context.

6.4.1 PERFORMANCE

The HSHS demolition resulted in the highest costs out of all scenarios at approximately $1,900,000 compared to $1,664,000 for the BAU case and $1,260,000 for the WCS (approximately $250,000 greater than BAU and $640,000 than WCS) (Table 10). The best practice demolition also resulted in the highest cost savings however, generating around $252,000 of benefits compared to $75,000 for the BAU case and $0 savings from the WCS (Table 9). Adding these costs and benefits together showed HSHS was the most expensive of the three scenarios, and presents possible reasoning as to why best practice measures are not often adopted.

It is evident from these results that performing a demolition with best practice techniques is costlier. However, the benefits generated outweigh the additional costs in terms of avoided waste costs, avoided raw material costs and revenue generation. One of the largest factors in these cost quantities were the waste fees. BAU had the highest waste fees, followed by WCS and HSHS had the lowest (Figure 9). This was due to the large quantity of waste recycled onsite (68% at HSHS), which meant less fees were paid to facilities to deal with this waste, and represents a significant benefit. Savings in this area for HSHS were approximately $500,000 from the BAU case. In all other categories, the HSHS site generated the highest costs. Most significant were the labour and machinery hire headings, accounting for approximately 55% of the best practice costs (Figure 11). This is due to the large amount of labour necessary for source separation to occur and the extended timeline because of this. In addition, the extra machinery (including crushing machinery and excavator use) also increased the overall costs.

The highest costing individual subheadings were labour and security expenses, accounting for \$370,000 (18.98%) and \$340,000 (17.24%) of the total costs individually (it should be noted that security costs are derived from both labour for security guards and “machinery” such as cameras and light tower hire). The high security costs were directly related to the length of the demolition timeline. The further the process timeline lengthened due to latent asbestos finds and crushing delays, the longer security was needed for, and the higher this cost becomes. As previously mentioned in Section 5.2, these delays amounted to a total of 131 and 51 days of delays for latent finds and crushing approvals respectively.

Interesting to note were the fuel costs of the WCS (Figure 13). These costs accounted for around 10% of total costs for the WCS demolition scenario, which is within the same percentages felt by the HSHS and BAU scenarios which both transported their waste shorter distances. This shows that the avoidance of waste levy payments at an increased transport cost is economically viable when comparing the cost of the total demolition, and possibly one of the incentives for such a practice. High machinery and labour costs discourage best practice demolition for those companies which take part in illegal waste management practices. Fuel use costs accounted for the second lowest category for the HSHS demolition.

6.4.2 IMPROVEMENTS

Overall, a superficial look at the higher costs in labour and machinery headings for the best practice scenario at HSHS may discourage these practices to be widely adopted, however the benefits gained from best practice techniques can be seen to account for this. Taking on

Japan's example, lowering tax on labour and increasing the tax on raw material purchases may help to alleviate some of the costs for demolition companies, and further the benefits displayed in this example (see Table A 2).

Streamlining the demolition process to start crushing approvals earlier on in the demolition will help to alleviate the high security cost and achieve an even cheaper demolition. In addition, innovation in contaminated waste management could also help to alleviate the cost of contaminated waste disposal, and reduce the timeline of the demolition due to latent finds to further reduce the cost.

6.5 SIGNIFICANCE AND LIMITATIONS TO THIS STUDY

This overall research is significant in displaying the benefits of best practice demolition techniques in WA, and can provide an example of future projects to follow and build upon for achievement of similar or better economic and environmental results. In performing this case study, insight into the interconnected nature of economic, environmental and social/policy factors is shown, and this will be beneficial for future transitioning to a circular economy.

Limitations exist in the characteristics of the demolition building. The HSHS site was old and had a large quantity of contaminated waste, and as such the proportion of waste generation, machinery use, labour and associated costs would vary from site to site. In addition, the large benefits derived from onsite reuse and recycle may not be applicable to smaller applications (such as residential demolition).

Limitations also exist as the benefits/costs and GHG abatement/emissions were compared to specific cases informed by current industry practices. The comparison to different cases may vary and as such the measured performance could also vary. These estimations may change over time as the current C&D waste management practices change and transition towards circular economy and best practice management. This data would therefore be limited in applicability to such cases. However, the data gathering of the HSHS demolition may still be able to be compared in those instances, and as such this research is still relevant. In applying this research to other countries, care should be taken in determining the costs of each economic category (i.e., labour, security etc.).

In addition to this, limitations exist in the reliability of the data. Data gathered from Merit using tip receipts often did not use weigh cells to generate these receipts, as is the current BAU approach to data collection for C&D waste. Further investigations and quantifying actual waste outputs from facilities could be an avenue for future research, building on the data generated in this thesis.

7 CONCLUSION AND RECOMMENDATIONS

This study achieves the aim, and four objectives outlined at the beginning of this thesis. More specifically:

Objective 1: *"Gain an understanding of current issues or innovations within the C&D waste sector"*. This was achieved throughout the study with stakeholder interviews, demolition observations and overall economic and environmental benefits observed. Issues were identified to include the illegal practices, and strict requirements which have implications on demolition cost and discourage best practice.

Objective 2: *"Identify the waste contribution of the HSHS demolition to the WA waste stream and stockpiling, and if this could be further improved"*. The demolition contributed low amounts of waste to stockpiling and the C&D waste stream (approximately 810 t, consisting mainly of general waste). This could be further improved upon with innovation in contaminated waste reclamation or possible waste to energy initiatives, and direct reuse.

Objective 3: *"Determine the environmental impacts/savings of conducting a demolition and potential construction using WA best practice".* This demolition displays the net abatement of GHG emissions achievable with best practice techniques. This could be further improved by using low emission machinery, which accounted for the largest proportion of total GHG emissions

.

<u>Objective 4:</u> *"Determine the economic viability of conducting best practice demolition in WA".* Using best practice demolition techniques can result in an input of spending for increased labour, machinery use and timeline related costs, however the benefits from raw material use avoidance and lowered transport and fuel costs accounts for this spend. Further discouragement is necessary for WCS transport to regional areas and avoidance of the landfill levy.

The HSHS demolition project was conducted with best practice demolition techniques to result in cost and environmental impact savings, and a high diversion from landfill (92%, which is close to the 95% and 97% from Netherlands and Japan [9]). The interconnected nature of the economic and environmental impacts is shown through the GHG savings and cost savings achieved with the input of crushing activity and direct recycle. The input of spending and a small increase of GHG emissions for onsite crushing results in net benefits of increased revenue and savings of both money and GHG emissions compared to the BAU case. Policy factors such as improper implementation of the landfill levy can lead to significant environmental impacts, and loss of important C&D material which could be utilised to reduce the pressure on stockpiling activity. This thesis measures the predicted effect of the worst-case scenario (WCS) which results from ineffective policy implementation.

It is recommended that regulations surrounding the landfill levy should be put in place to discourage a WCS outcome. Further economic incentives could be applied to further encouragement of sustainable demolition activity, such as lower labour taxes and higher raw materials tax. This should be further investigated along with research conducted on the implementation of design for deconstruction, and studies of how to improve application of direct reuse in future redevelopments. The focus of the WA Waste Strategy 2030 (2019) on the circular economy is valid and achievable if correct incentive is provided and managed. This study is beneficial in the C&D waste industry, to display environmental and economic incentives of conducting demolition projects with best practice measures, and will contribute to the efforts towards transitioning towards a circular economy.

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APPENDICES

1 APPENDIX - LITERATURE REVIEW

TABLE A 1 ANALYSIS OF GLOBAL LEGISLATION AND ACHIEVED RESULTS

Region	Policy and legislation	Description	Most recent C&D waste Diversion

European Union - General	• Construction 2020 Strategy - EU Construction and Demolition Waste Management Protocol
	• EU Waste Framework Directive (2008/98/EC)
	• Landfill, incineration, and PAYT schemes
	• Cohesion Fund
		• Improve confidence in C&D waste products through:
		  o Improved waste identification, source separation and collection
		  o Improved waste logistics
		  o Improved waste processing
		  o Quality management
		  o Appropriate policy and framework conditions
		• Set targets and set reporting requirements (Waste Framework Directive - 70% of the non-hazardous C&D waste stream to be recycled before 2020)
		• Invest in waste collection infrastructure and establish economic instruments to enhance management
		• Establish extended producer responsibility schemes (EPR)
		• Establish "polluter pays" principle to develop attitudes towards sustainable waste practices
			50% (average across member countries)

Japan	• Construction Material Recycling Law (2000) • "Sound Material-Cycle Society" and development of the Fundamental Plan (2000, 2008 and finally 2013)	• Recycling of certain demolition materials is mandatory • Improve resource productivity while simultaneously reducing waste output • Reduce weight of weight disposed by tonnage • Increase landfill limitations and	97%

		• Focus on the 3R concept (although still involving incineration within the 3R strategy, which is seen as a less sustainable practice) • Become less reliant on importing resources and achieve long-term economic sustainability	
Netherlands	• Construction Products Directive • Soil Quality Decree (SQD) • Ban on C&D waste landfill • Prohibition for mixing wastes of different quality, separation at source	• Decrease C&D waste landfilling, reduce conventional demolition (destructive, co-mingled) • Ban disposal of otherwise reusable waste materials for enhancement of CE • SQD: o Regulation on emissions of building materials o Improve end quality to improve uptake of material and minimize environmental impacts o Create acceptable cost (minimize double testing in supply chain)	95%
USA and Canada	• **USA:** Federal Highway Administration (FHWA) Recycled Materials Policy • **SF**: San Francisco Zero Waste Program	• Specify use of recycled materials in construction, and are to be prioritized before other materials • 100% diversion of waste from landfill (SF) • Increase diversion rate from landfill and incineration (SF) • Pay As You Throw (PAYT) programs (SF)	70% and 73% respectively
Spain	• Legislation and regulations to promote on-site waste sorting	• Sets out C&D waste management obligations which must be followed by all relevant stakeholders in construction	Under 15%
China	• Chinese Green Building Certification Standard (2014)	• Only the ground foundation and structural elements are required to design for C&D waste reduction	5%

[4, 25, 9, 59, 26, 10, 18]

TABLE A 2 FACTORS EITHER CONTRIBUTING TO OR INHIBITING EFFECTIVE C&D WASTE MANAGEMENT

These have also been found to align with CE barriers

	Social	Economic	Political/Legislative	Technical
Barriers to effective C&D waste	• Lack of confidence in C&D waste products (often because of lack of regulations on quality) (China) • Poor awareness and behaviour from stakeholders (including contractors) (Spain) • Lack of awareness of the environmental impacts of landfilling (Spain) • Cultural resistance, where attitudes towards recycled products are not favourable (China)	• Legal requirements are too expensive for small businesses to keep up with (Spain) • Lack of market for recycled C&D waste products (Japan, Australia, China) • Low cost of disposal compared to recycling (China) • Higher cost of recycled products compared to virgin materials (Japan) • Increase in landfill levies leading to illegal dumping (Australia, China)	• Lack of regulation on C&D waste management • Lack of regulation on recycled C&D waste products quality (China) • Poor communication and coordination among parties involved (Australia, • Lack of urban planning leading to low building life expectancy and high demolition generation (China) • Inaccurate data reporting and collection methods (Australia, • Uncertain definitions of C&D waste and quantification (Europe)	• Lack of recycling facilities and large travel distances increasing environmental impact (China) • Poor project processes and activities during demolition/construction (China, Spain)
Contributing factors to effective C&D waste management	• Positive contractor awareness and attitudes towards C&D waste management (Netherlands, Japan) • Fostering recycling culture • Increase confidence in recycled C&D waste materials • Increase education on recycling and reuse processes • Cultural ideologies	• Increase landfill levies (Australia, SF) • Increase tax on raw materials, lower tax on labour (to create market and high demand for recycled C&D waste products) (Japan, Australia) • Ban C&D waste sent to landfill (Netherlands) • Create a market for recycled C&D waste products	• Regulate how data is presented and take measures to increase comparability (European Union) • Regulation concerning illegal dumping and higher penalties • Regulations and specific policy elements should emphasise technical recommendations for the use of recycled C&D waste products	• On-site separation of materials and on-site processing • Waste Management Plans • Better project design in construction, and following those designs • Pre-fabrication of construction materials or designing for deconstruction

[9, 39, 15, 60, 14, 34]

TABLE A 3 A SUMMARY OF THE MAIN WASTE MANAGEMENT LEGISLATION AND POLICY

Legislation	Description
Waste Avoidance and Resource Recovery (WARR) Act 2007	• Main legislation for waste management in WA • Established the Waste Authority to o "provide strategic policy advice to the State Government o implement policies, plans and programs consistent with the Waste Strategy o apply funding to strategic initiatives" • Preparation and implementation of State Waste Strategy (2012) and the WARR Levy Act (2007)
Waste Avoidance and Resource Recovery Regulations 2008	• States procedure, requirements and fees involved for waste permit applications, and fines associated with non-compliance
Waste Avoidance and Resource Recovery Levy Act 2007	• States levy charges to waste received at landfill sites, which can provide funds for the Waste Authority to invest in future development • Levy set to increase to discourage disposal of recyclables
Waste Avoidance and Resource Recovery Levy Regulations 2008 and Policy 2009	• Requirements necessary for disposal of waste to landfill, and the assessment and calculations involved in landfill levy charges
Environment Protection Act 1986 (EP Act)	• Primary legislation for waste regulation to prevent, control and abate pollution and environmental harm. Specifically: o health implications from dust and noise o transport and stockpiling requirements o Flora and fauna control o Illegal dumping prevention o Emissions prevention and related fines (including site run-off)
National Waste Policy: Less Waste, More Resources (2009)	• directs waste management across Australia, establishing 16 key strategies for waste management (however it has been suggested that there has been little action from the government to implement these strategies)
Western Australian Waste Strategy (2012)	• provide knowledge, infrastructure and incentives to change behaviour regarding waste • Focuses on waste hierarchy • Sets waste targets (C&D waste 75% diversion by 2020)

Environmental Protection Regulation (controlled waste)	• States correct handling of hazardous materials, and establishes action taken for lack of compliance

[20, 21, 27, 23, 5]

TABLE A 4 ANALYSIS OF CE VIABILITY FOR SPECIFIC MATERIALS IN THE C&D WASTE STREAM

Material	Circular Economy Viable?	Reasoning
Cement	No, direct reuse suggested	• Cement is abundant, cheap, strong and convenient. • Low price of production due to high efficiency of current process is main driver, leads to little motivation to change current processes. • Cement should be reframed as an exotic material to be used sparingly • Reducing impacts relies entirely on reducing its production
Steel and Iron	Limited possibility	• CE could occur if steel is recycled with perfect cleanliness • CE possible if reduction of number of compositions of steel occurs to simplify recycle loops. • Demand reduction is the key strategy for reducing environmental impacts.
Paper	No	• CE possible if instead of recycling paper, paper cleaning occurs for reuse, however this is unlikely • As with steel and cement, highly efficient current process leads to low prices and low motivation to change the current processes, hard to change process globally
Wood	Not considered	-
Plastic	No	• If composition is changed to be uniform for all applications, then there is an energy benefit • This is not suggested to be likely due to efficient current process and overhaul needed across countries of current processes
Textiles	Possible	• Possible with repair and maintenance of textiles as manual labour is needed and has low environmental impacts due to this
Glass	No	• CE would not save much energy compared to a linear economy • Reducing quantity produced is key to reducing impacts
Aluminium	Possible	• Possible with increased separation and collection from mixed waste streams

[37]

TABLE A 5 METHODS FOR C&D WASTE QUANTIFICATION

Method	Description	Usefulness
Site visits	Direct (e.g. weighing quantities) or indirect (e.g. surveys of waste piles) measurements are taken for a realistic survey. On-site interviews can also be taken with professionals to verify production rate	Not appropriate for C&D waste generation estimation at regional levels, but is of great importance to project level analysis. Direct measurements are the most practical method, and provide good, actual data
Generation rate calculation (GRC)	Involves calculating a waste generation rate (in kg/m2 or m3/m2) derived from waste statistics, financial values or area-based calculations	Useful at both regional and project levels, and is widely used, however it is not suggested if direct measurements can be made
Lifetime analysis	This is mainly used when estimating only demolition waste output, and involves a mass balance assuming all construction materials will become (and therefore equal) demolition wastes, and the lifetime of the building/materials	Can be used in regions where no demolition data exists. Lifetime of buildings is more useful at a regional level, whereas lifetime of materials is more useful at a project level
Classification system accumulation	This is based on the GRC method, and involves a classification system (based on existing systems such as the European Waste List (EWL) for quantifying a specified material. This is useful for both construction and demolition activities.	Can be used at a project level, and a more detailed understanding of the waste generation nature is necessary
Variables modelling	C&D waste generation is very site specific and depends on a range of factors as previously stated. Using this method, C&D waste quantification can be achieved through predicting the relationships between these factors which provides systematic information to aid decision making.	Due to the lack of available C&D waste data, this method is only conceptual for C&D waste, and is unreliable for future predictions. More investigations necessary.

[29]

2 APPENDIX – METHODS

TABLE A 6 COMPARISON SCENARIO FEATURES

Scenario	Description	Specific Activities
WCS	Worst case scenario, all comingled waste to landfill and avoidance of levy by transport to regional areas. Low economic impacts prioritised.	- All materials are co-mingled; the only materials may have been separated are hazardous materials to be disposed of at an appropriate facility
		-very short timeline, often termed "smash and grab"
		-Assumes all materials used for construction onsite are not recycled
		-Clearing all useful land for maximization of profit
		-Main motivator is time and money
BAU	"Normal", business as usual (BAU) demolition with comingled waste generation, and majorly transported to processing facility. Metal salvage occurs due to profitability in most cases. Low economic impacts prioritised.	- All materials are co-mingled, the only materials may have been separated are hazardous materials to be disposed of at an appropriate facility, and metal (to a lesser extent than HSHS)
		-may result in lowered water use due to less crushing activity needed and shorter timeline
		-Assumes All materials used for construction onsite are not recycled, unless it is the cheapest option
		-Clearing all useful land for maximization of profit
		-Main motivator is time and money
HSHS	HSHS Demolition: most similar to a deconstruction, prioritising direct reuse onsite, low processing and limited transport of wastes offsite. Low economic and environmental impacts prioritised.	- **Separated** waste stream generated
		-**Direct reuse** of crushed material, some timber (flooring, jarrah), some whole bricks which meet requirements/specs, aesthetic features, mulch
		-**retaining some flora and fauna**, some relocated to be brought back onsite during construction
		-Main motivator is environmental impacts, some economic motivations

[46]

TABLE A 7 SCENARIO CALCULATION SPECIFICS FOR COMPARISON

Environmental Analysis Scenario Changes from HSHS		
Section	BAU % of HSHS Scenario	WCS % of HSHS Scenario
Machinery - Water Truck	70% Reduced timeline results in less dust suppression needed from water truck	30% Very short timeline, lower dust suppression needed from water truck
Machinery - Semi tipper (MCG)	50% Less onsite stockpiling, not used for offsite transport	0% Assumed semi-tipper not used for offsite transport, no stockpiling onsite
Machinery - Crushing Equipment	0% Not used for BAU	0% Not used for WCS
"CAT1" - 20t excavator	100% Used to load waste	100% Used to load waste
"CAT2" - 20t excavator	100% Used to load waste	100% Used to load waste
"CAT3" - 36t excavator	50% Used for demolition and no pulverizing (pre-crushing activity)	30% Used for small amount of demolition, no pulverizing
Transport	Extra transport from 8614.28 t of waste not directly used/recycled onsite (332 extra loads of waste for transport based on truck volume of 26t/load added to HSHS travelled distance)	All waste transported to regional facility (447 loads travelled total of 34389 km)
Economic Analysis Scenario Changes from HSHS		
Section	BAU portion of HSHS Scenario	WCS portion of HSHS Scenario
Salvaged Benefits	90% of metal salvage only No other materials separated onsite for salvage, and metal salvage would not have occurred to the HSHS extent (observed extra measures taken on HSHS site which were not economically beneficial such as removing table legs)	0% No separation of materials so no salvage benefits
Equipment Hire	30% Minus floor strippers equipment rent	30% Minus floor strippers equipment rent
Sea Containers	0% Not used for BAU (needed for noise suppression in crushing activity)	0% Not used for WCS (needed for noise suppression in crushing activity)
Trucking/Transport	5% Includes bobcat and loader for separation of bulk masonry materials, some metals	0% No separation of materials onsite

Permits and Licenses	0% No crushing activity needed	0% No crushing activity needed
Tipping fees (mixed waste)	(Eco resources cost/tonnes of General waste)*Total BAU waste (11036t) More materials to deal with due to the no onsite reuse/recycle (crushed materials, timber, cleaned bricks, mulch), higher cost	Total mixed WCS waste (11036)* regional tipping fee of $48/t [61]
Tipping fees (contaminated material)	Same	Regional tipping fee of $84/t used [61]
Machinery Fuel Cost	Machinery fuel usage (derived from above percentages for machinery usage)	Machinery fuel usage (derived from above percentages for machinery usage)
Transport Fuel	Based on the extra distances calculated from above. 55L/100km of fuel assumed [62] and $1.40/L (Steve King, pers. comm.)	Based on the regional travel as outlined above, and assumptions for fuel same as BAU
Subcontracts	Minus brick cleaning, sea container labour, and 70% of remaining labour amount due to less separation of materials onsite	70% of BAU amount, Labour still used however to a lesser extent
Security costs	5% Demolition team suggested a quicker timeline and no salvage kept onsite means no security is needed	5% Same as BAU
Environmental Services	Minus mulching and tree relocation from HSHS, the rest is the same for dust suppression services, asbestos and environmental advice, sign offs	Same as BAU
Wages and Salaries	70% Less separation of materials leading to lower labour costs	70% of BAU amount, Labour still used however to a lesser extent
Crushing	0% No crushing	0% No crushing

TABLE A 8 DENSITY DATA USED FROM WA WASTE AUTHORITY TABLES

Material	Conversion Factor
Aluminium cans - whole	0.026
Aluminium cans - flattened	0.087
Aluminium cans - baled	0.154
Car Batteries	1.125
Car battery - 1 battery	*0.0125*

E-waste	0.24
Glass bottles - whole	0.174
Glass bottles - semi-crushed	0.347
Greenwaste processed	0.3
Greenwaste unprocessed	0.15
Greenwaste unprocessed compacted	0.26
Inert (mixed) waste	1.3
Other Textiles	0.15
Putrescible (mixed) uncompacted waste	0.3
Putrescible (mixed) compacted waste	0.425
Paper / Cardboard	0.1
Plastic containers - whole	0.01
Plastic containers - whole, some flattened	0.013
Plastic containers - baled	0.139
Rubber	0.3
Steel cans - whole	0.052
Steel cans - flattened	0.13
Steel cans - baled	0.226
Wood / Timber	0.3

[63]

TABLE A 9 DENSITY DATA FROM NATIONAL WASTE CONVERSION TABLES

Waste Material	Density - kilograms per cubic metre		
	Low	Medium	Compact
Vegetation - Garden	91	227	445
Garden - trees	150	450	900
Wood - Timber	156	156	156
Wood - Furniture	160	170	400
Wood - MDF	156	156	156
Tyres - Rubber	200	200	400
Glass	411	411	411
Low level contaminated soil	922	922	922
Clean fill/soil	950	950	950
Rubble	1048	1048	1048
Concrete	830	830	830
Tiles	900	1500	2000
Brick	828	828	828
Sand	1000	1000	1000
Asphalt	680	680	680
Plasterboard	227	227	227
Insulation	60	100	350
Cement Sheets	830	830	830

[64]

TABLE A 10 PRIMARY DENSITY DATA GATHERED ONSITE

In-Situ data	Description	Result	Unit
Mass of cleaned bricks	The weight of 1 cleaned brick was derived from weighing a series of bricks from different brick stacks. The result is the average gained from this process	3.8	kg/brick
Density of mulch	A known volume of mulch was collected in a bucket and weighed (minus the bucket weight) from different stockpiles, and various repetitions. This was then combined with the demolition estimate (1m3/0.4t) to get an average value for mulch density*	0.3	t/m3

TABLE A 11 EMISSIONS FACTORS FOR EACH CATEGORY OF GHG EMISSION CALCULATION

Crushed Rock (Aggregate, drainage material 50mm)				
Name	Value	Unit	Source	Assumptions
Aggregate (e.g. crushed rock)	0.007	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	"Mine to End of Production" boundary = Emission factory boundary includes all offsite activities required to extract raw materials, transport and produce them. Scope 3
Crushed rock base	0.0064	t CO2-e/t	Mitchell (2012) and RMCG (2010) [48]	Not given
Road Sub-base (Crushed 20mm material)				
Name	Value	Unit	Source	Assumptions
Limestone sub-base (crushed)	7.1	kg CO2-e/t	Australian Database RMIT (2007) [48]	Mining stage to material production including quarrying and crushing (scope 3) WA study
Crushed rock base	6.4	kg CO2-e/t	Australian Database RMIT (2007) [48]	Mining stage to material production including quarrying and crushing (scope 3), WA study
Bricks				
Name	Value	Unit	Source	Assumptions
Bricks (Common bricks)	0.39	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Bricks	0.5512	t CO2-e/t	ICE Database (Hammond and Jones 2011)	
Ordinary Brick	0.271	kg CO2-e/kg	European ecoinvent database (2007) [65]	European location, Scope 1 and 3 (including construction demolition of building and disposal)
Metals (Aluminium, brass, copper, steel)				
Name	Value	Unit	Source	Assumptions/ Boundary
Aluminium	8.571	kg CO2-2/kg	European ecoinvent database (2007) [65]	Not given
Primary Aluminium	20.680	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Recycled Aluminium	1.660	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Copper	5.150	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Copper	1.999	kg CO2-e/kg	European ecoinvent database (2007) [65]	European location, Scope 1 and 3 (including construction demolition of building and disposal)
Recycled Copper	0.112	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3

Virgin Steel	2.190	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Recycled Steel	1.060	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Structural Steel	1.050	t CO2-e/t	Greenhouse Gas Assessment Workbook for Road Projects [57]	Mine to end of production, Scope 3
Reinforcing steel	1.526	kg CO2-e/kg	European ecoinvent database (2007) [65]	European location, Scope 1 and 3 (including construction demolition of building and disposal)
Transport (diesel use for medium to heavy goods)			***Energy content of Diesel fuel= 38.6 GJ per kL, and can assume approximately 5.6L of diesel is used per km if conversion is necessary (as suggested by https://www.bitre.gov.au/publications/2009/files/wp_073.pdf) (although should be noted that with conversion using estimation results become inaccurate)**	
Name	**Value**	**Unit**	**Source**	**Assumptions**
Heavy goods vehicles*	2.14E-13	t CO2-e/km	Greenhouse Gas Assessment Workbook for Road Projects [57]	Indirect (scope 2 and 3) emission, specifically scope 3 "Emissions from the combustion of fuel when transporting materials"
Transport fuel emissions	See notes	t CO2-e/kL	National Greenhouse Accounts Factors [55]	Scope 1 emissions, based on heavy vehicle type (Conforming to Euro design standards)
Road Lorry (20-28t	0.193	kg CO2-e/km	European ecoinvent database (2007) [65]	European location, Scope 1 and 3 (including construction demolition of building and disposal)
Articulated truck	0.124	kg CO2-e/tkm	Australian database RMIT 2007 [48]	Mining stage to material production including quarrying and crushing (scope 3) WA study
Machinery fuel use				
Name	**Value**	**Unit**	**Source**	**Assumptions**
Diesel	2.887	t CO2-e/kL	Greenhouse Gas Assessment Workbook for Road Projects [57]	Includes direct and indirect emissions (scope 1 and 3) (i.e., emissions from the direct combustion of diesel, and the indirect emissions from producing the diesel)
Diesel	2.680	t CO2-e/kL	Greenhouse Gas Assessment Workbook for Road Projects [57]	Direct (scope 1) emissions only
Stationary combustion of diesel (liquid fuel)	See notes	t CO2-e/kL	National Greenhouse Accounts Factors [55]	Scope 1 emissions
Electricity use				
Name	**Value**	**Unit**	**Source**	**Assumptions**
Electricity use (WA)	0.00082	t CO2-e/kWh		Scope 2 (electricity use)

	0.00092	t CO2-e/kWh	Greenhouse Gas Assessment Workbook for Road Projects [57]	Both Scope 2 and 3 (both use and electricity lost in transmission)
South West Interconnected System (SWIS) in WA	0.00070	t CO2-e/kWh	National Greenhouse Accounts Factors (Department of Environment and Energy, July 2018)	Indirect, scope 2 for purchase of electricity quantity, and is specific to area of WA case study is in
WA electricity mix	0.000868	t CO2-e/kWh	Australian database RMIT (2007) [48]	Scope 2 emissions

[57, 55, 48, 65]

NOTE: NGER guidelines convert kL to GJ using an energy content factor, which then uses emission factors for CO2, CH4 and N2O with relevant oxidation factors incorporated in calculations. Output is t CO2-e, and 3 separate calculations for each GHG. This is performed in this way as fuels used for transport purposes produce slightly different CH4 and N2O emissions than if the same fuel was used for a stationary energy purpose.

Highlighted lines in green have been used in calculations as they have been determined to be applicable to the requirements of this case study calculations.

3 APPENDIX – CALCULATION RESULTS

TABLE A 12 MATERIAL QUANTIFICATION GENERATED FROM TIP RECEIPT DATA

Material name	Individual waste	Final volume (m3)	Density (t/m3)	Final Mass (t)
Steel/Metals	**Total metals**	Displaying in tonnes [A]		**332.9**
	Aluminium			5.4
	Brass			0.9
	Copper			2.9
	Lead			0.1
	Steel			322.7
	Stainless Steel			0.9
Mixed Bricks/Concrete	**C&D non-inert**	Displaying in tonnes		**24.3**
General Waste	**Total general waste**	**2975.0**	-	**2025.8**
	Mixed rubbish	2793.0	0.70	1971.4
	General work	20.0	0.70	14.0
	Not specified	40.0	0.70	28.0
	Anticon [B]	120.0	0.10	12.0
	Tyres [C]	2.0	0.20	0.4
Timber	**Total timber**	**60.0**	-	**18.0**
	Theatre flooring, gym floor	20.0	0.30	6.0
	Building G, Roofing, timbers	40.0	0.30	12.0
Greenwaste	Vegetation which can't be mulched	**20.0**	0.15	**3.0**
Asbestos Materials	**Total asbestos materials**	Displaying in tonnes		**40.9**
	ANZ			29.1
	Asbestos			3.2
	Pipes/ACM			8.6
Asbestos Concrete	**Total Asbestos concrete**	540.9	0.83	**734.5**
	Gutters	540.9	0.83	449.0
	Canteen roof	Displaying in tonnes		86.4
	Building B			199.2
Contaminated soils	**Contaminated soils**	690.0	0.92	**636.2**
	TOTAL	7861.81	NA	6967.66

Colour	Meaning
(purple)	Using density data from the Waste Authority tables Table A 8.
(pink)	Confirmed with demolition crew or survey data
(blue)	Derived from density calculations using primary data
(green)	Using national density data (Victoria, see Table A 9)

Notes:

A – Where it says, "displaying in tonnes", no volume data was available, however all data is to be displayed in mass units.

B – Medium density is assumed

C – Tyres were not generated from activity onsite they were illegally dumped

TABLE A 13 MATERIAL QUANTIFICATION FROM ESTIMATES AND SURVEY DATA

Material name	Number	Volume (m3)	Density (t/m3)	Mass (t)
Timber for firewood	NA	120	0.42	50
Timber salvage for resale	NA	80	0.50	40
Crushed brick	NA	Displaying in tonnes		1716
Crushed concrete	NA			4612
Crushed mixed material	NA			1948
Mulched	NA	380	0.300	114
Cleaned bricks	40,000	~3.8kg per brick		152

TABLE A 14 TRANSPORT EMISSION CALCULATIONS AND COST ACROSS ALL SCENARIOS

Waste type	Hamilton Hill Used	Distance away from HSHS (km, one-way trip) ^	Number of times travelled	Additional way-back trip *	Total distance travelled to facility (km)
General Waste	Eco Resources	14.1	151	68	3087.9
Contam, C&D non-inert	Brajkovich Landfill & Recycling (South)	10.1	25	9	343.4
Contam, Greenwaste, General waste	Brajkovich Salvage (north)	55.3	6	0	331.8
Metal Salvage	AAA Recycling	20.0	108	52	3200
Metal Salvage	Rondas	23.1	17	6	531.3
Timber Salvage	Timber Hardwood Trader	6.2	4	0	24.8
Contam	Waste Stream Management	18.9	60	27	1644.3
				Total	**9163.5**

Transport avoided from onsite crushing:	Transport to Eco Resouces:	14.1	318	317	**8962.2**

	BAU facility the same as HSHS	Distance away from HSHS (km, one way trip)^	Number of times travelled	Additional way-back trip *	Total distance travelled to facility (km)
General waste	Eco Resources	14.1	151	68	3087.9
Contam & C&D non-inert	Brajkovich Landfill & Recycling (South)	10.1	25	9	343.4
Contam	Brajkovich Salvage (north)	55.3	6	0	331.8
Metal	Rondas	23.1	17	6	531.3

Metal	AAA Recycling	20.0	108	52	3200
Contam	Waste Stream Management	18.9	60	27	1644.3

Extra waste generated from no on-site recycle						
Additional material needed to process (no direct onsite reuse)	**BAU facility additional transport**	**Quantity added**	**Extra loads****	**Number of times travelled**	**Additional way-back trip ***	**Total distance travelled to facility (km)**
Cleaned Bricks	Brajkovich Landfill & Recycling (South)**	152 t	5.8	30.8	14.8	461.5
Extra timber and crushed material	Eco Resources	8384 t	322.5	473.5	390.5	12181.3
Mulch	Brajkovich Salvage (north)	78.28 t	3.914	3.9	2	327.0
					Total	**22108.6**

BAU facility - worst case with transport to regional area	**Quantity added**	**Loads****	**One-way distance to Facility^**	**Number of times travelled**	**Additional way-back trip ***	**Total distance travelled to facility (km)**
Transfer Station (all waste to landfill, illegally avoiding levy)	11036.0	424.5	71.10	423.0	422.0	30497.3
Contaminated waste still separated	**1411.6**	**54.3**	71.10	54.0	53.0	3892.4
Total	**12447.5**				**Total**	**34389.7**

**assumption made if multiple trips travelled in one day as per raw data analysis*

***assuming a load size of 26t per trip on a 20m3 truck as suggested by waste authority density tables*

****average of 20 m3 per load, adding the 4 loads assumed from HSHS*

^Distance measurements taken from google maps, the fastest route

*Avoided Levy cost (all waste, 11036 t * $70): $772,517.87*

TABLE A 15 MACHINERY FUEL USAGE FOR ALL SCENARIOS

HSHS Demolition Machinery Fuel Usage

Total fuel usage given

Machine	Total Fuel Usage (kL, diesel)
Water Truck (14,000L)	10.8
Semi Tipper MCG (6 wheeler 20m^3)	31.5
Urban Resources Plant and Equipment	13.3
Total	**55.6**

Fuel Usage from data sheets (3 excavators)

Machine	Fuel Usage - Idling (kL, diesel)	Fuel Usage - Working (kL, diesel)	TOTAL (kL)
CAT1 20T Excavator	0.4	4.2	4.6
CAT2 20T Excavator	1.2	15.1	16.3
CAT3 36T Excavator	0.7	16.0	16.7
Totals (kL)	**2.3**	**35.3**	**37.7**

Total fuel usage (kL) 93.3

BAU (with metal recycle) Fuel Usage

Total fuel usage given

Machine	Total HSHS Fuel Usage (kL, diesel)	BAU fuel usage
Water Truck	10.8	**7.56**
Semi Tipper MCG	31.5	**15.75**
Urban Resources Plant and Equipment	13.3	**0**
Total	**55.6**	**23.31**

Fuel Usage from data sheets (3 excavators)

Machine	HSHS Fuel Usage - Idling (kL, diesel)	BAU Idling fuel	HSHS Fuel Usage - Working (kL, diesel)	BAU Working fuel	BAU Totals (kL)
CAT1 20T Excavator	0.4	0.4	4.2	4.2	4.6
CAT2 20T Excavator	1.2	1.2	15.1	15.1	16.3
CAT3 36T Excavator	0.7	0.4	16.0	8.0	8.4
Totals	**2.3**	**1.9**	**35.3**	**27.4**	**29.3**

Total fuel usage (kL) 52.6

Worst case scenario (WCS), all waste transported regionally

Total fuel usage given

Machine	Total HSHS Fuel Usage (kL, diesel)	WCS fuel usage
Water Truck	10.8	3.24
Semi Tipper MCG	31.5	0
Urban Resources Plant and Equipment	13.3	0
Total	55.6	3.24

Fuel Usage from data sheets (3 excavators)

Machine	HSHS Fuel Usage - Idling (kL, diesel)	WCS Idling fuel	HSHS Fuel Usage - Working (kL, diesel)	WCS Working fuel	WCS Totals (kL)
CAT1 20T Excavator	0.4	0.4	4.2	4.2	4.6
CAT2 20T Excavator	1.2	1.2	15.1	15.1	16.3
CAT3 36T Excavator	0.7	0.2	16.0	4.8	5.0
Totals	2.3	1.8	35.3	24.2	26.0
Total fuel usage (kL)	29.2				

Note: Smaller tip trucks and ute not included as they were seldom used, and tree removal equipment as vegetation removal unable to be estimated based on area, and relocation emissions unknown. It should be noted that carbon storage is not set to be largely effected, due vegetation relocation back onsite, and high amount of greenspace allocation in POS is predicted to offset removal.

TABLE A 16 COST OF TRANSPORT FUEL FROM TRANSPORT CALCULATIONS

	Distance Travelled (km)	Fuel Used (L)	Cost (1.40/L)
HSHS	9163.5	5094.91	$7,132.87
BAU	22108.6	12292.35485	$17,209.30
WCS	34389.7	19120.6732	$26,768.94

(assuming average of 55.6L/ 100 km, and the cost per L of fuel as determined by Merit demolition team [62])

TABLE A 17 BREAKDOWN OF HSHS EMISSIONS CALCULATIONS

HSHS (negative values indicate benefit to GHG emissions and less emissions)

Effect on overall emission	Demolition Activity	Amount	Unit	Emission Factor	GHG Emission (t CO2-e)
+	Machinery Use (Total large items)	80.0	kL	2.887	230.84
+	Electricity Usage (Office Building)	7407.0	kWh	0.001	5.18

				Emission Factors			Emissions (t CO2-e)			
		Amount (kL)	Energy Content Factor (GJ/kL)	CO2	CH4	N2O	CO2	CH4	N2O	Total GHG Emission (t CO2-e)
+	Crushing Activity (stationary diesel combustion)	13.3	38.6	69.2	0.1	0.2	35.526	0.051	0.103	35.68

				Emission Factors			Emissions (t CO2-e)			
	Transport Emissions	kL Fuel	Energy Content Factor (GJ/kL)	CO2	CH4	N2O	CO2	CH4	N2O	Total GHG Emission (t CO2-e)
+	Direct Transport	5.095	38.6	69.9	0.1	0.5	13.747	0.020	0.098	13.86

Avoided Transport to Crushing Facility	-4.983					-13.445	-0.019	-0.096	-13.56

Direct Avoided Virgin Material Use	Amount (t)	Emission Factor	GHG emission avoided (t CO2-e)
50mm crushed material (drainage aggregate)	907	0.007	-6.349
20mm crushed material (sub-base)	7369	7.1	-52.320
Brick	152	0.39	-59.280

Total Demolition Activity Emissions			271.708
Total Demo Activity and Transport Emissions			285.57
Total avoided emissions from recycle (including avoided transport)			-613.54
		Net	-327.97

Potential Avoided Virgin Material Use	Amount (t)	Raw Emission Factor	Recycled Emission Factor	GHG emission from raw material (t CO2-e)	GHG Emission from Recycled Material (t CO2-e)	Saving (t CO2-e)
Aluminum	5.390	20.68	1.66	111.465	8.9474	-102.518
Steel	322.740	2.19	1.06	706.801	342.1044	-364.696
Copper	2.942	5.15	0.112	15.151	0.329504	-14.822

TABLE A 18 BREAKDOWN OF BAU EMISSIONS CALCULATIONS

BAU Case - no crushing activity, higher transport emissions, lower demolition activity emissions, no directly avoided 50mm and 20mm material emissions

Effect on overall emission	Demolition Activity	Amount	Unit	Emission Factor	GHG Emission (t CO_2-e)
+	Machinery Use (Total large items)	52.6	kL	2.887	151.88
+	Electricity Usage (Office Building)	7407.0	kWh	0.001	5.18

			Emission Factors			Emissions (t CO_2-e)			
Transport Emissions	kL Fuel	Energy Content Factor (GJ/kL)	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	Total GHG Emission (t CO_2-e)
Direct Transport	12.292	38.6	69.9	0.1	0.5	33.166	0.047	0.237	33.45

Potential Avoided Virgin Material Use	Amount (t)	Raw Emission Factor	Recycled Emission Factor	GHG emission from raw material (t CO_2-e)	GHG Emission from Recycled Material (t CO_2-e)	Saving (t CO_2-e)
Aluminum	4.851	20.680	1.660	100.319	8.947	-91.371
Steel	290.466	2.190	1.060	636.121	342.104	-294.016
Copper	2.942	5.150	0.112	15.151	0.330	-14.822

Emissions from Virgin Material Use	Amount (t)	Emission Factor	GHG emission avoided (t CO2-e)
50mm crushed material (drainage aggregate)	907	0.007	6.349
20mm crushed material (sub-base)	7369	7.1	52.320
Brick	152	0.39	59.280

Total Demolition Activity Emissions			157.067
Total Emissions from using raw materials			117.95
Total Emissions			308.47
Total avoided emissions from recycle			-400.21
		Net	-91.74

TABLE A 19 BREAKDOWN OF WCS EMISSIONS CALCULATIONS

Worst Case Scenario - transport of all wastes regionally for disposal and waste levy avoidance

Demolition Activity	Amount	Unit	Emission Factor	GHG Emission (t CO2-e)
Machinery Use (Total large items)	29.2	kL	2.887	84.29
Electricity Usage (Office Building)	7407.0	kWh	0.001	5.18

			Emission Factors			Emissions (t CO2-e)			
Transport Emissions	kL Fuel	Energy Content Factor (GJ/kL)	CO2	CH4	N2O	CO2	CH4	N2O	Total GHG Emission (t CO2-e)
Direct Transport	19.121	38.6	69.9	0.1	0.5	51.590	0.074	0.369	52.03

Emissions from Virgin Material Use	Amount (t)	Emission Factor	GHG emission avoided (t CO2-e)
50mm crushed material (drainage aggregate)	907	0.007	6.349

Total Demolition Activity Emissions			89.470

20mm crushed material (sub-base)	7369	7.1	52.3199
Brick	152	0.39	59.28
		Total	117.9489

Total Emissions from using raw materials			117.95
Total avoided emissions			0
		Net	**259.45**

TABLE A 20 HSHS MAJOR COST BREAKDOWN

Cost Heading	Cost ($)	Percent of total	Subtotals
Labour		**23.99%**	-$472,661.40
Brick Cleaning	-$30,800.00	1.56%	
All other	-$373,934.20	18.98%	
Security	-$67,927.20	3.45%	
Machinery Hire		**31.25%**	-$615,654.37
Security	-$271,708.80	13.79%	
Repairs	-$6,480.98	0.33%	
Bobcat and loader	-$34,157.41	1.73%	
Crushing Equipment	-$90,553.64	4.60%	
Sea containers for noise	-$32,895.81	1.67%	
Equipment Hire	-$75,082.73	3.81%	
Mulching/tree removal	-$104,775.00	5.32%	
Fuel		**10.67%**	-$210,146.49
Transport estimation (not minus rebate)	-$7,132.87	0.36%	
Fuel (truck and subcontractor)	-$72,450.18	3.68%	
Machine Use estimation (not minus rebate)	-$130,563.44	6.63%	
Waste fees and Enviro Services		**31.15%**	-$613,782.30
Mixed waste	-$118,333.00	6.01%	
Contaminated waste	-$342,367.85	17.38%	
Contam services	-$153,081.45	7.77%	
Misc. Smaller costs		**2.94%**	-$57,942.35
Standpipe	-$1,879.62	0.10%	
Gases	-$3,363.25	0.17%	
Lab Testing + Consultancy Fees	-$2,165.00	0.11%	
Small tools, equipment and materials	-$19,678.29	1.00%	
Services and disconnection	-$9,276.60	0.47%	

Safety and safety equipment	-$21,579.59	1.10%	
TOTAL COSTS	-$1,970,186.91		

TABLE A 21 BAU MAJOR COST BREAKDOWN

Cost Heading	Cost ($)	Percent of total	Subtotals
Labour		15.43%	-$274,257.49
Brick Cleaning	$0.00	0.00%	
All other	-$257,275.69	14.48%	
Security	-$16,981.80	0.96%	
Machinery Hire		1.73%	-$30,713.67
Repairs	-$6,480.98	0.36%	
Bobcat and loader	-$1,707.87	0.10%	
Crushing Equipment	$0.00	0.00%	
Sea containers for noise	$0.00	0.00%	
Equipment Hire	-$22,524.82	1.27%	
Mulching/Tree Removal	$0.00	0.00%	
Fuel		9.19%	-$163,312.15
Transport estimation (not minus rebate)	-$17,209.30	0.97%	
Fuel (truck and subcontractor)	-$72,450.18	4.08%	
Machine Use estimation (not minus rebate)	-$73,652.67	4.14%	
Waste fees and Enviro Services		61.74%	-$1,097,161.33
Mixed waste	-$601,712.03	33.86%	
Contam Waste	-$342,367.85	19.27%	
Contam Services	-$153,081.45	8.61%	
Misc. Smaller costs		3.14%	-$55,777.35
Standpipe	-$1,879.62	0.11%	

Gases	-$3,363.25	0.19%	
Lab Testing + Consultancy Fees	$0.00	0.00%	
Small tools, equipment and materials	-$19,678.29	1.11%	
Services and disconnection	-$9,276.60	0.52%	
Safety and safety equipment	-$21,579.59	1.21%	
Materials Purchase		8.77%	-$155,847.00
50mm drainage aggregate	-$15,419.00	0.87%	
20mm road base	-$88,428.00	4.98%	
Bricks	-$52,000.00	2.93%	
TOTAL COSTS	-$1,777,068.99		

TABLE A 22 MAJOR COST BREAKDOWN WCS

Cost Heading	Cost ($)	Percent of total	Subtotals
Labour		13.90%	-$197,074.78
Brick Cleaning	$0.00	0.00%	
All other	-$180,092.98	12.70%	
Security	-$16,981.80	1.20%	
Machinery and Equipment Use		5.00%	-$70,915.80
Repairs	-$6,480.98	0.46%	
Machinery Hire (bobcat and loader)	$0.00	0.00%	
Crushing Equipment	$0.00	0.00%	
Sea containers for noise	$0.00	0.00%	
Equipment Hire	-$22,524.82	1.59%	
Enviro Services	-$41,910.00	2.96%	
Fuel		9.88%	-$140,091.88
Transport estimation (not minus rebate)	-$26,768.94	1.89%	
Fuel (truck and subcontractor)	-$72,450.18	5.11%	
Machine Use estimation (not minus rebate)	-$40,872.76	2.88%	

Waste fees		56.53%	-$801,378.19
Mixed waste	-$529,726.54	37.36%	
Contam Waste*	-$118,570.20	8.36%	
Contam Services**	-$153,081.45	10.80%	
Misc. Smaller costs		3.70%	-$52,414.10
Standpipe	-$1,879.62	0.13%	
Gases	$0.00	0.00%	
Lab Testing + Consultancy Fees	$0.00	0.00%	
Small tools, equipment and materials	-$19,678.29	1.39%	
Services and disconnection	-$9,276.60	0.65%	
Safety and safety equipment	-$21,579.59	1.52%	
Materials Purchase		0.00%	-$155,847.00
50mm drainage aggregate	-$15,419.00	1.09%	
20mm road base	-$88,428.00	6.24%	
Bricks	-$52,000.00	3.67%	
TOTAL COSTS	-$1,417,721.76		

** derived from regional disposal cost of $48/t*

*** derived from regional ACM disposal cost of $84/t*

TABLE A 23 BREAKDOWN OF BENEFITS

Material	Quantity	HSHS cost	BAU cost	Unit	Total HSHS cost	Total BAU cost	Saving Generated
Drainage Material (50mm crushed material)	907	0	$17.00*	$/t of 50 mm material	$0.00	$15,419	$15,419.00
Road base (20mm crushed material)	7369	0	$12.00*	$/t of 20mm material	$0.00	$88,428	$88,428.00
Cleaned bricks	40000	$0.77	$1.30	Per brick	$30,800.00	$52,000	$21,200.00

Reduced landfill levy paid**	10226	0	$70.00***	$/t of inert waste	$0.00	$715,795	$715,795.47
					Subtotal	$871,642	
					Salvage		$96,948.31

* *Includes transport cost of $7/t*

** *landfill levy exemption for asbestos containing materials (ACM), but does not include soils or waste mixed with ACM that could be separated*

*** *Rate as of 1 July 2018*

4 APPENDIX – INTERVIEW TRANSCRIPTIONS

Name in thesis: Stakeholder A
General Role (thesis description with anonymity): Important stakeholder involved in communication between industry and government, with extensive experience. Interview only

What are the major problems in the C&D waste industry of WA?

- In the past there was no real action, there were goals but not any actual commitment by government. The draft Waste Strategy 2030 is the first real step towards bettering C&D recycling in WA.
- Massive "leakage" of material at the moment – they can't account for about 1 to 1.5 million tonnes of C&D waste (2015-2016) which was identified in the waste report
- This issue is caused by the landfill levy not applying to regional areas of WA, in combination with voluntary reporting from transfer stations which lie on the border of where the metro area turns regional
- Companies can get out of paying the landfill levy for a load if they transport their waste to these bordering transfer stations, and if the transfer stations falsify the origin of this waste then no one will know that the waste is from the metro area
- This is like what has previously been seen in NSW since 2002, where waste is transported over the border to Queensland in order to avoid levy fees. The government can't control trade across the border, so really integration of waste control across the states throughout Australia needs to be a goal.
- Protection against this comes under the EPA, and not within criminal law, so the risk for this activity will not be met with too bad of a punishment. Likened to a "slap on the wrist"
- Back in 2012 recycled C&D waste was attempted to be reused in construction, however this process failed due to exceedances in contamination
- Lack of understanding was present from the demolition contractors involved, which did not understand that the product they were creating had such strict QA controls
- These exceedances made govt. wary of recycling C&D waste, and so the recent developments for the industry are massive for WA.

<u>Side question –</u> Do you see an issue with the way DWER responds to problems arising (illegal dumping, massive leakage of waste) Stakeholder A replied with a general no, it's hard for them to monitor without whistle-blowers (and not many want to jeopardise their career to make a complaint), and very hard for them to prove.

What are the major solutions to these problems?

- A much tougher reporting regime is necessary, which needs to be compulsory.
- Extend the landfill levy to regional areas. At possibly a reduced rate which may reflect the context/distance of the facility.
- Fix regulations on transfer stations (which he said is "the easy bit", compared to behaviour change which is far more difficult)
- Mandatory weigh bridges IN CONJUNCTION with monitoring (i.e., cctv footage or online data)
- Very strict controls and assurance measures need to be in place to prevent another 2012 disaster. If the current WA Main Roads project widening of the Kwinana freeway fails this will be another massive setback for the industry.
- Side question – "Do you think there is too much "red tape" in terms of these controls on contamination?" Stakeholder A confidently replied with no, they are a necessary aspect of recycle products to be able to be used, and there will be no market without them.

What are some of the major innovations/contributors to higher C&D recycle in WA at the moment?

- Major emphasis on WA Main Roads trial. If this is successful in WA this will lead the way for far more C&D waste recycle and reuse, and could create a knock-on effect for local governments and key civil engineering companies such as GHD
- Victoria has the best recycle of C&D in Australia so far in terms of road base and recycled aggregates, which Stakeholder A suggests is due to the rigorous monitoring by govt. bodies throughout the process (from cradle to grave of a building), which needs to be compliant all the way through (in terms of contamination)
- Landfill levy is a good economic instrument, however it needs controls (fix regulations at transfer stations and fix the application of the levies to regional areas)

Would new products be beneficial in market development?

- All we need to do is to get road base on board. Even if we crush all of the C&D waste available this wouldn't meet demand. Upscaling of products needed
- The demand is already high, but we could make more sophisticated products where value is increased and therefore profit increases
- Supports design for deconstruction for CE, first time it has been discussed

Generalised comments

1. Illegal transport of waste to regional areas (resulting from improper implementation of the landfill levy, and under regulated transfer stations) a big problem which needs to be dealt with
2. New draft Waste Strategy 2030 focus on CE step in the right direction

3. Strict testing is necessary to increase the perception of C&D products, and assure quality
4. Data collection and reporting needs to improve
5. Use of recycled C&D for road base highly beneficial

Name in thesis: Stakeholder B
General Role (thesis description with anonymity): Important stakeholder involved in resource recovery for a prominent waste companies in WA – and site visit

General facility info

- In general deal with a large quantity of WA's C&D waste stream, with facilities across Perth metro and regional areas
- Recycled sand is still sold to the civil sector, the only main issues are the colour and low permeability, however it is very compactible which can save GHG emissions
- Use GPS tagging and a robust accreditation process to ensure the quality of their products. Opinion of their recycled waste products need to be kept high, and this is achieved with independent accreditation and branding
- Third party testing of products allows confirmation that foreign contaminants are limited. This gives certainty to buyers that the product is able to be used. Downside is this is more expensive.
- Facility does charge less for separated materials. Comingled waste still relatively high

What key waste quantities generated from C&D activity not accounted for in the recycling stream? How/why?

- Plastics recycling is often not in Australia, don't currently have a way to deal with bulk plastics
- Commercial demolition it is easier to control waste, for smaller residential demolition it is harder to coordinate any processes (small area, lots of contractors etc.).
- MDF wood products – often used for cabinets, school desks, made of sawdust (which could be harmful to health if breathed in) and currently unable to process, and is one of the major timber contaminants
- Wood flooring lined with resins which can't be recycled, and the same with stone benchtops
- No asbestos acceptance (not licensed for disposal)

What are the major problems in the C&D waste industry of WA?

- Travel distances have huge influence over economic feasibility. Recycle markets must be closer than virgin material markets for it to be a viable option
- Illegal transport of waste to regional areas
- Main roads – not as economically viable to sell products to them due to the strict testing requirements which cost 4x greater than selling to civil projects. RCPP replaced by RTR pilot but possibly won't work due to the strict testing regime.
- Other smaller companies are thought of to be illegally operating as they process more waste than reported, and therefore need the correct licenses. Without correct licenses, incorrect disposal of wastes can occur. Doesn't believe smaller-scale

operations will work based on needed infrastructure. Suggests regulators are overstretched
- Other stakeholders may be personally motivated due to their involvement with landfilling or other facilities
- Politics can be a bit idealistic, focusing on plastics when they only account for a small proportion of the waste stream, however suggests focus should be on the most environmentally harmful materials

Would new products be beneficial in market development?
- Recycled concrete being reformed into concrete, can use fly-ash to replace the virgin component you need to reform it back into concrete.
- Seawalls (good for the predicted sea level rise resulting from climate change) constructed with Nano-hydrocarbons in concrete curing, so the reinforcing steel is not needed. Usually the steel can cause these sea walls to break, so this is a significant innovation which will also reduce raw material use.

Is market development a barrier to greater C&D waste recycle in WA?
- Struggling to find a market for recycled C&D products, and stockpiling was a problem due to the perception of waste products (being bad quality)
- Perception of product was low due to main roads not being able to use their products unless they complied

What are the possible solutions to the identified problems?
- Possible automation could lower transport costs
- Recycle wastes here and use the recycled products in Australia, no export or import and losing economic benefit
- Waste to energy facilities could deal with the residual unrecyclable wastes (such as the plastic waste stream and other streams which are currently sent to landfill)
- Set up a commodity market that can stand on its own two feet without subsidy (i.e., create a market). Possibly sell recycled concrete for $8 per tonne so there is a viable market for this product
- Plastics recycling processes work over east as they have the volume to support the process, whereas WA suggested this is not the case.
- SASA model worked in SA in which concrete is sold to recyclers, whereas here we pay recyclers to deal with the waste material. Recycled concrete has a higher value.

Generalised comments:

4. Robust accreditation and quality assurance measures help to improve recycled product quality, and opinion surrounding the product quality
5. The cost of strict testing requirements is too high for Main Roads recycle, if products can be sold to other areas for cheaper prices (due to less strict testing regime)

6. Market development is necessary, especially if extra testing requirements are needed to increase C&D material recycle and quality assurance to increase public perception of C&D products
7. Smaller companies operating illegally without licenses could present a problem, as waste management at these facilities is not as monitored or regulated with licensing requirements. Illegal transport of waste to regional areas is also a problem, however not a newly observed one
8. Transport costs are high and often deciding factors in where waste is dealt with (i.e., either processing or landfill), and automation could help to alleviate the economic pressure of transporting waste
9. Plastics, MDF and resin-treated wood are problems as they cannot be recycled and often contaminate otherwise separated, recyclable waste. Finding ways to deal with these proportions (such as waste to energy) would further enhance circular economy efforts
10. More work needs to take place in the area of regulation to improve C&D waste reuse and recycle

Name in thesis: Stakeholder C
General Role (thesis description with anonymity): Regional transfer station and landfill owner – and regional site visit/tour

General facility info

- Receives mainly comingled waste, sometimes just sand. Facility does charge less for separated materials
- Truck dumps waste, excavator brings in for sorting light materials and screening for sand removal (lowers transport cost), through to processing at the landfill/processing facility
- Services the larger southwest regional area
- All wastes (including contaminated waste) accepted
- Reporting compulsory as part of DWER licenses
- As trucks move in/out, sheet signed stating waste origin, vehicle type (for volume estimation, no weigh bridge at the facility), date
- Also have extractive license and sell raw materials as well as recycled C&D waste

What are the major problems in the C&D waste industry of WA?

- Illegal dumping on farming land – some trucks come to facility and state the price they want to pay to dump the material. IF not accepted, sometimes illegally dumped. This is not often reported to DWER under whistleblowing due to the requirements of this process
- DWER red tape has prevent recycle of some waste such as greenwaste (dieback), stringent testing for contaminated materials prevented recycle at one point. Also suggested that there is a lack of action by DWER to punish illegal activity
- Refuse acid sulphate soils (ASS) as there was no demand for its disposal and may contaminate groundwater (which is monitored). Storage of this material is too expensive to conform with requirements
- Lack of government support

Is market development a barrier to greater C&D waste recycle in WA?

- Suggested the market is “all a money game”
- Must give away recycled sand away for free, large stockpiling evident (of recycled sand and recycled materials) due to low value. Owner suggests this is the case for most recycled materials, low market for them due to low perception of quality
- There is some market for recycled products as they are cheaper than the raw materials
- Lack of market for the recycled sand is largely impacted by people’s mindset of the sand and impacts how it moves

- Low uptake of the 20-40mm crushed material, sometimes sold to landscapers. Stockpiles increasing.
- Glass crushing used to take place, however the product wouldn't sell so this practice stopped as it was no longer economically viable

What are the possible solutions to the identified problems?

- Practical waste sorting initiatives need to be put in place, and education about recycling and how to recycle different products needs to improve (example of Canada and their waste recycling education programs sued as a good example)

<u>Generalised Answers:</u>

1. DWER testing and controls are too strict
2. Illegal dumping is a problem for regional areas
3. Lack of market leads to slow movement of some recycled wastes

4.1 SHORTER INTERVIEWS WITH LESS STRUCTURED QUESTIONS

Name in thesis: Stakeholder D – email communication
General Role (thesis description with anonymity): Residential C&D waste sector
(Francis Burke)

What are the major problems in the C&D waste industry of WA?

- Stringent noise and dust suppression requirements for crushing licenses (more than civil works)
- Missed opportunity at Shenton Hospital development where onsite crushing did not take place due to delays and perceived risk issues from Landcorp

What are some of the solutions to this?

- Showing cost and CO_2 savings from onsite crushing important, and may lower license requirements

Name in thesis: Stakeholder E – unstructured interview
General Role (thesis description with anonymity): Waste consultant, extensive experience
Michael Norris
General

- BAU= some source separation as it is cheaper than landfill

What are the major problems in the C&D waste industry of WA?

- At the moment no Australian standard on waste rating systems which is necessary to enhance education and separation at source
- Available waste information can be hard to understand and lacks uniformity
- Stockpiling problem with quantification related to standardisation and acceptance of recycled product
- Eclipse vs state – resulted in reworking guidelines, then application of RCPP

Name in thesis: Stakeholder F – unstructured interview
General Role (thesis description with anonymity): Demolition waste company director with many years of experience in the C&D waste industry
Steve King

Problems/considerations:

- Stockpiling and illegal transport of waste are problems
- Extra sorting time vs the cost (labour, machinery, fuel, safety issues)

- Double storey buildings less likely to have materials separation due to the logistics of it, usually destructive demolition. Roll-on effect if demolition timeline pushed back that results in higher costs
- Most of the time salvage value is not worth the extra cost and time inputs

Incentives for higher recycle/reuse

- Cost of landfill driven economic benefits and less material disposal